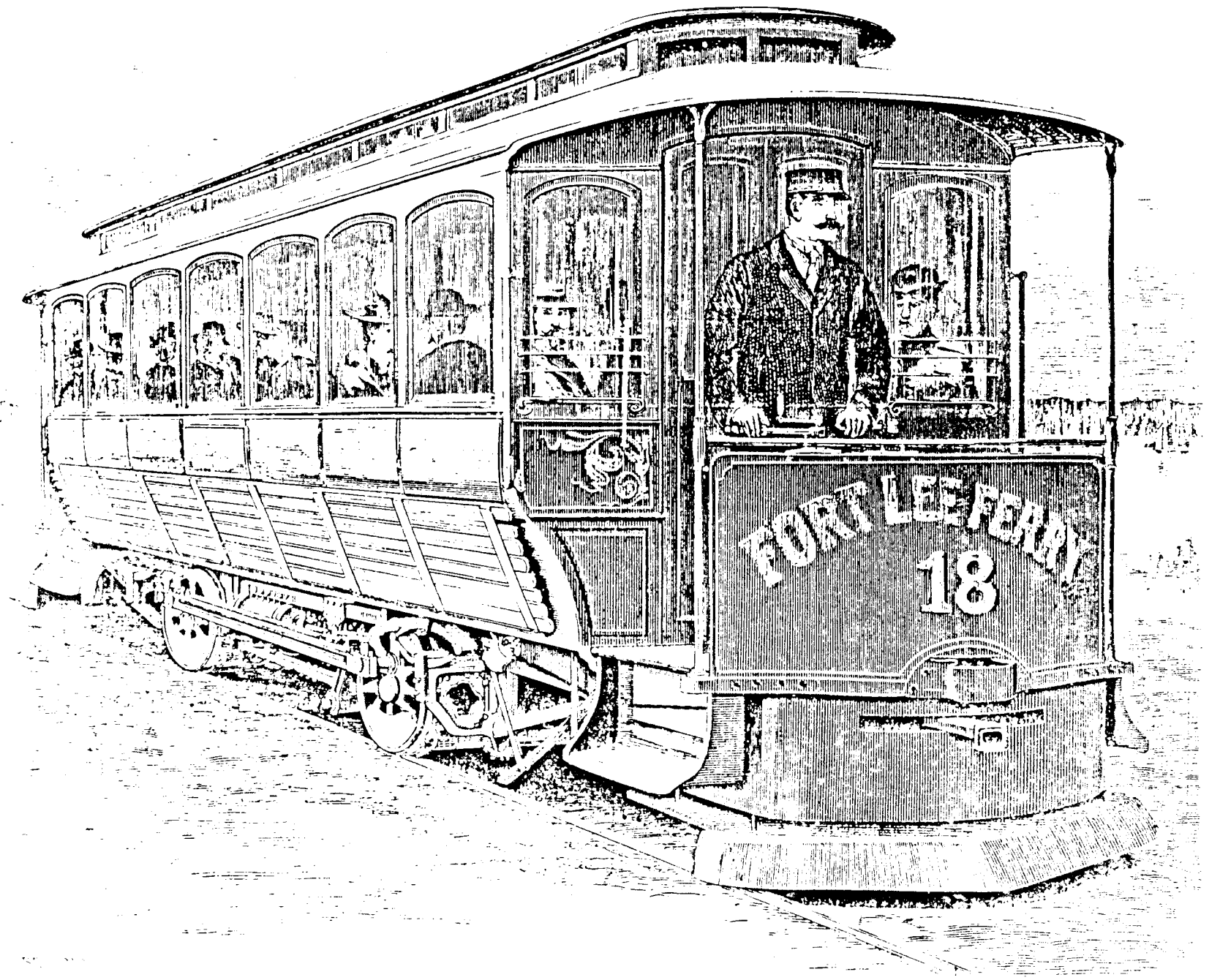
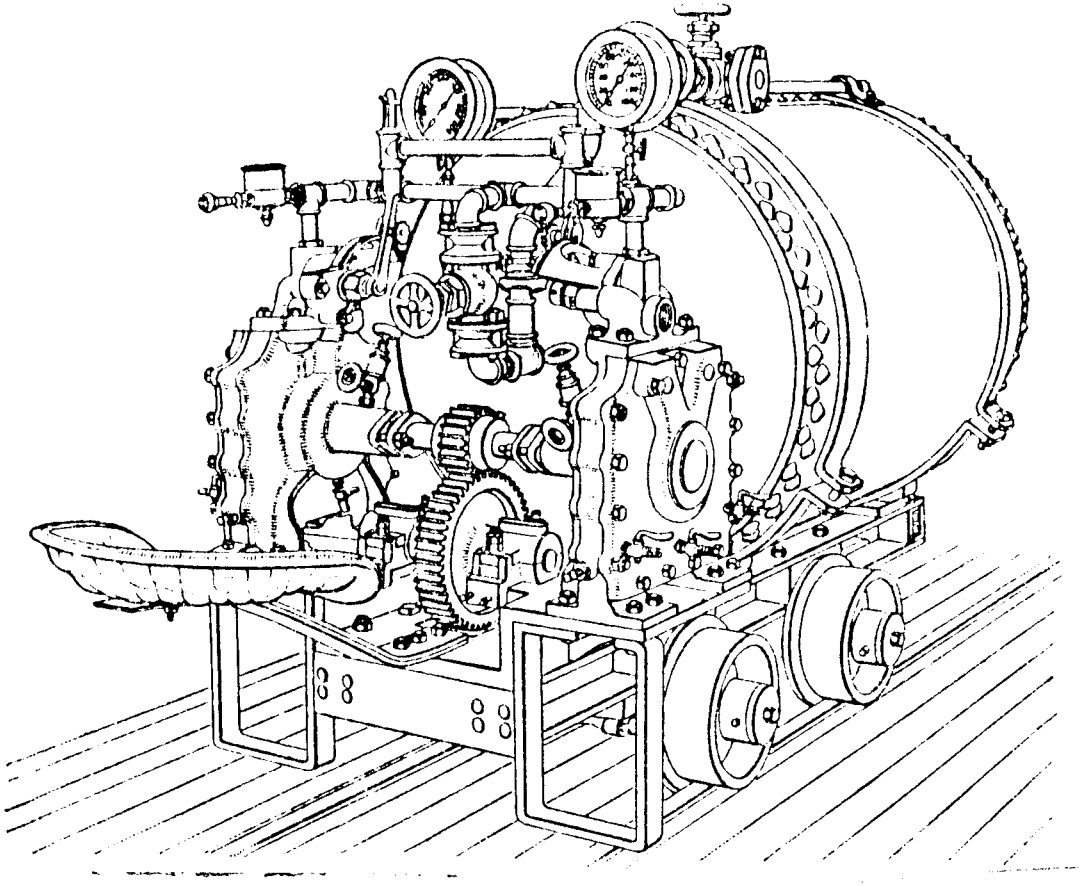
The Truth about Air Cars
100 Years of Documentation

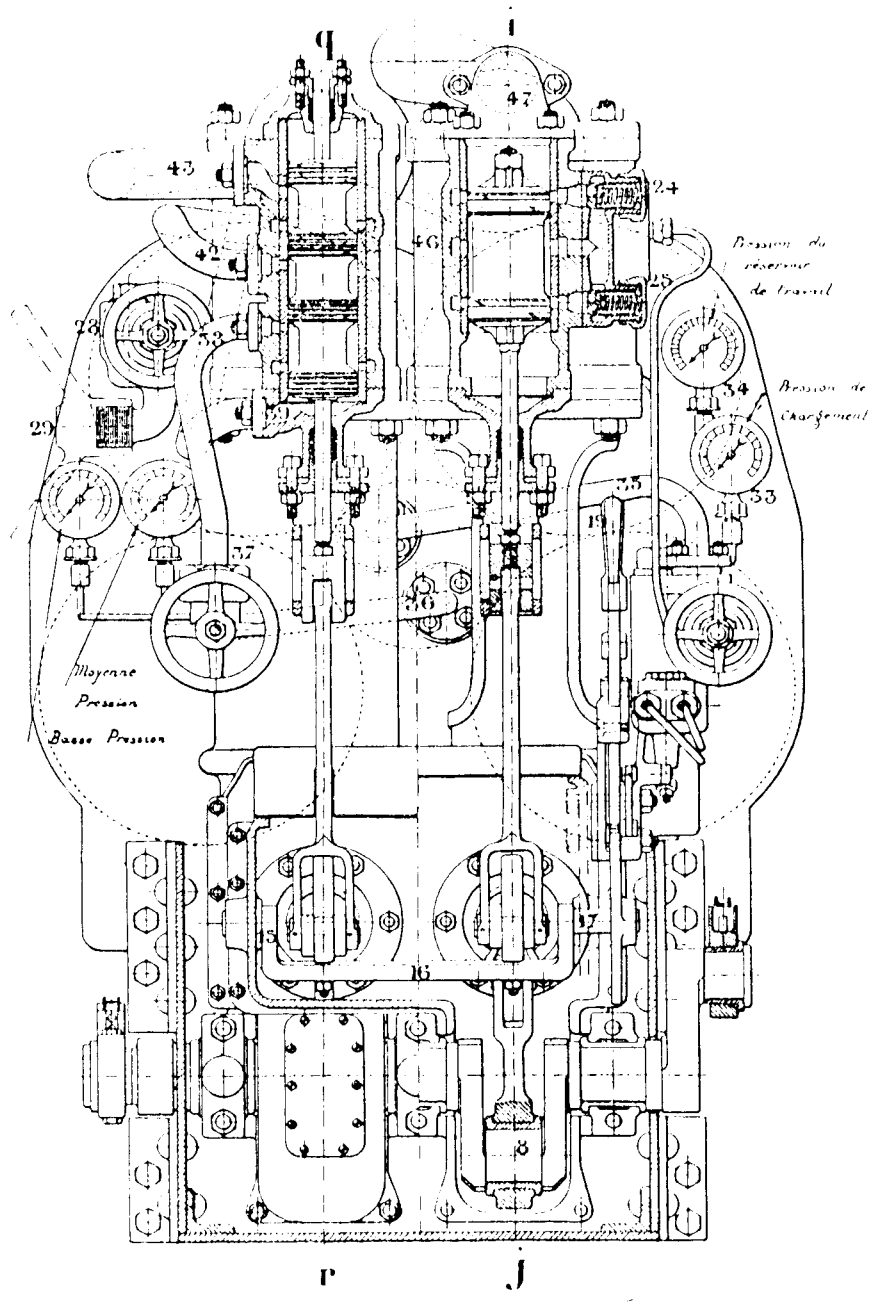
compiled by Luther Rangely



THE HARDIE COMPRESSED AIR MOTOR CAR.

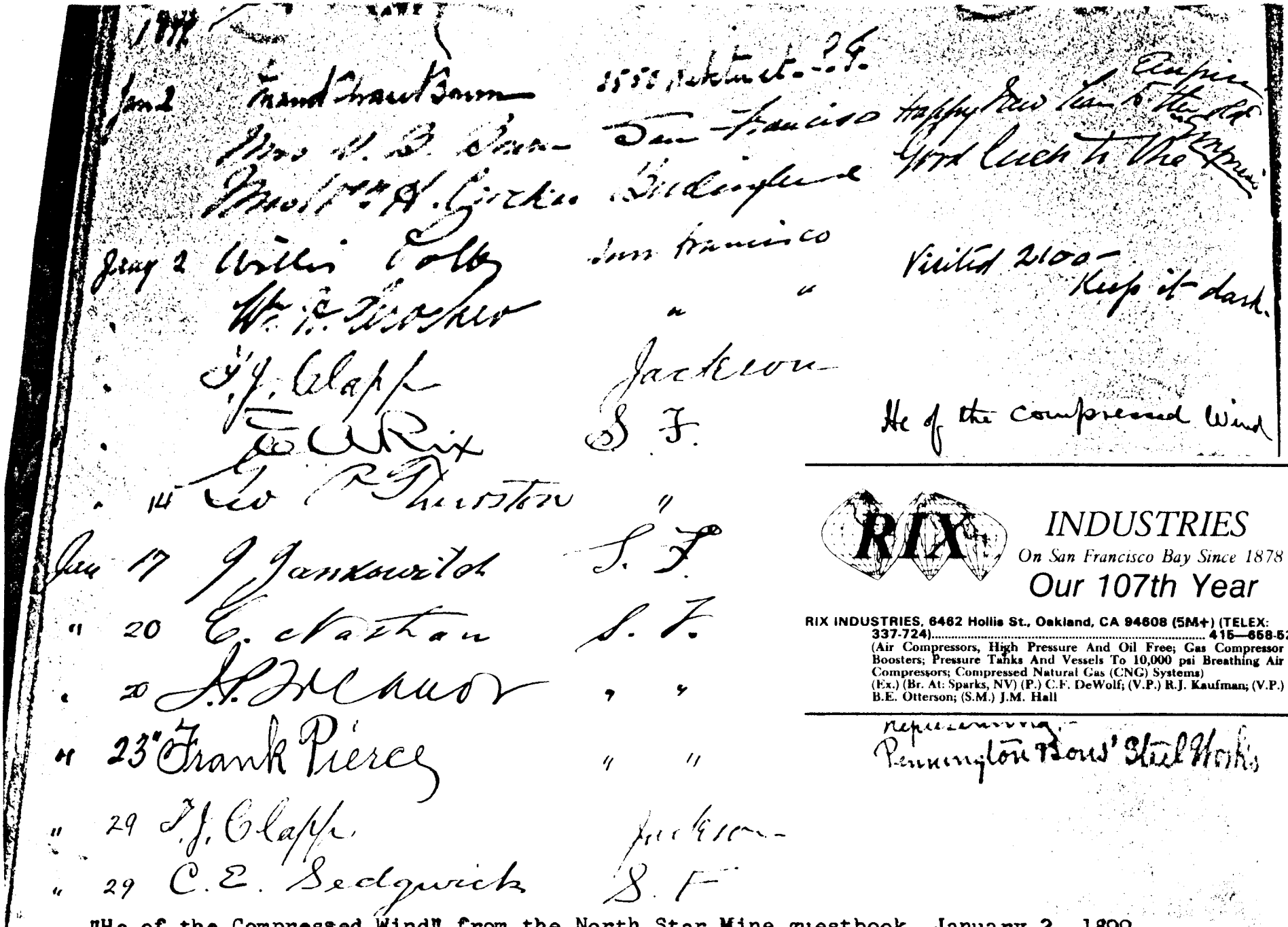


Empire Mine, Grass Valley, Cal. Several small compressed-air locomotives, built by Edward A. Rix, are employed in the deep levels of the mine, for hauling trains of 5 cars, each carrying 1 ton. The maximum distance covered by a round trip is about 5,000 ft. Locomotive storage tank measures 36 ins. diameter × 48 ins. long, carrying a pressure of 500 lbs. The dimensions over all are only 5 ft. long × 30 ins. wide × 52 ins. high, the gauge of track being 18 ins. One of these locomotives (Fig. 209) is operated by a pair of vertical engines, a chain and sprocket drive connecting the crank-shaft with the rear axle. There are 2 tandem tanks, one of them being carried on a tender. A reheater, provided with a Primus kerosene burner, reheats the air after its pressure has been reduced in the auxiliary reservoir. Mr. Rix has recently built 3 similar locomotives, but with a single, larger tank, for a 3-mile tunnel, near San Francisco.



Triple Expansion Air Locomotive Engine: this design represents the most efficient air engines ever built, which were only used in Europe, while the double expansion air engine displaced all other pneumatic locomotive engines in the U.S.

THE TRUTH ABOUT AIR CARS
VOLUME 1



"He of the Compressed Wind" from the North Star Mine guestbook, January 2, 1899, Grass Valley, California. Edward A. Rix built compressed air locomotives for the neighboring Empire Gold Mine. The compressor manufacturing firm he founded is now worth over five million federal reserve notes in tangible assets.

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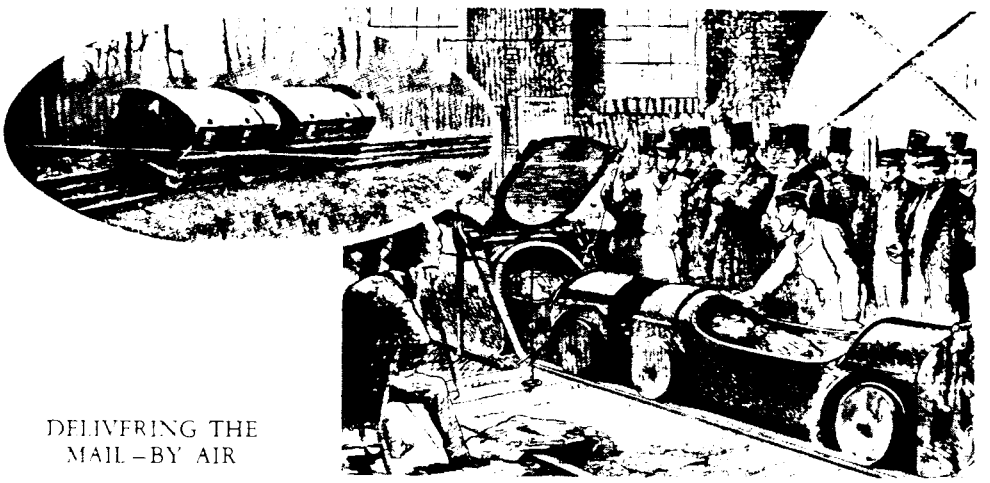
"The only known vehicle utilizing compressed air is a prototype of golf cart size built in Italy."

--Lawrence Livermore study, 1978

Strange Stories, Amazing Facts, Readers Digest, p. 199

MAN'S AMAZING INVENTIONS



DELIVERING THE MAIL—BY AIR

A practical use for the air-tube railway in February 1863. The first mailbags are sent speeding on their way from the post office's Northwestern District Office at Eversholt Street, London, through a pneumatic tube, to Euston Station. Inset: A 1914 variation of Brunel's system—the prototype of the electric train that now moves the mail around London in a similar way.

TRAINS THAT COULD RUN ON AIR

Early attempts to develop air-driven trains

Trains have been powered by steam, diesel oil, electricity, and, experimentally, jet and rocket engines. But in 1844 Isambard Kingdom Brunel, the great British inventor, built a train that was driven by air.

His plan was to pull a train along a tube between the tracks. The lead coach was attached to the 15-inch-diameter pipe by means of a piston arm.

Huge pumping engines every three miles along the track extracted air from the pipe in front of the train, and the pressure behind the piston forced it along.

Brunel built an experimental section of pipe on the South Devon Railway. But the copper and leather pipe valves corroded in the salty air and were chewed away by rats.

Seventeen years later another British inventor, T. W. Rammell, designed a system in which the whole train was blown and sucked along a tube. But the idea of huge tubes crisscrossing the country was unrealistic, and in 1870 pneumatic railways went underground.

That year a 312-foot-long model subway opened in New York beneath lower Broadway. Its 22-seat cars were driven like sailboats, by a blast of air.

But in 1880 electric trains seemed more promising, and the long search for a railway that could run on air was abandoned.

The above excerpts suggest that if you want to know the truth about air cars, don't ask Readers Digest or Lawrence Livermore Lab!

The Return of the Air Car

Because of its many advantages as a fuel medium, compressed air has been the subject of much research and development since the middle of the 19th century. Despite its advantages, and despite a thriving air powered locomotive market that grew steadily throughout the first quarter of this century, air powered transport is no longer taught to engineers or mentioned in textbooks. As a result, many researchers and inventors who become interested in the air car question find themselves trying to re-invent the air engine, unaware of the extensive literature already existing on the subject.

It's a good idea for anyone who wants to design an air car to first study the work of those who've designed air cars in the past. Fortunately, the air car faction had qualified technical people on its side for several decades, so a lot of detailed information was published in standard engineering textbooks and technical trade journals. Inventors shouldn't make the mistake of assuming that older textbooks are obsolete. The old compressed air books were written by hands-on experts who were mainly concerned with efficiency in the compression and use of air. Since the laws of physics, thermodynamics and those concerning the behavior of gasses are the same now as they were in 1887, the technical information published during the era of the compressed air locomotive is extremely useful to the modern air car inventor.

This book covers only non-self-fueling air cars, that is, air cars that have no compressor on board and must stop to refuel from stationary compressors. Information has been published, concepts have been patented, and claims have been made for self-fueling air cars, but much of this information is vague, incomplete or speculative and some is in obvious violation of the laws of physics. The writers of the air locomotive era wrote to educate, whereas modern inventors of self-fueling air cars sometimes publicize only to tantalize. Many inventors have never revealed their experimental results, much less the theories these results are supposed to prove.

So when someone sets out to design any type of air car, his best background material is the documented performance data of air cars of the past that were efficient enough to be successful on the market.

This book is dedicated to Terry Miller, the only modern air car inventor who has disclosed and documented his designs and results for the education of the public.

Scott Robertson
April 26, 1987

Compressed Air Motors in Cincinnati.

Mr. Geo. A. Clarke, of Cincinnati, has a project for street car propulsion by compressed air, an outline of which we give below, on the authority of the Cincinnati *Commercial Gazette*:

"Cars are constructed with double metal bottoms for air chambers. Compressed air which is known to be about ten per cent. more efficient than steam at the same pressure, will be utilized to run the car both forward and backward and stop and start it on any grade. By a simple contrivance the motion of the car continually replenishes the constantly exhausting air, but, of course, only partially. Means must be provided for refilling.

"At each end of the line is a simple twelve horse-power engine. The entire length of the line, between the tracks if double, or at the side of a single track, is laid fifteen inches beneath the surface, an iron pipe four or five inches in diameter. This is perfectly jointed, and every piece tested to stand a pressure of one hundred and twenty-five pounds. The engines keep this pipe constantly filled with air at a pressure of about one hundred pounds. At intervals of a square, this pipe will be tapped, and it is estimated that connection can be made with the car and pressure taken on in six seconds time. A pressure of eighty pounds to the square inch in the air chambers of the car will give a propelling force equal to six horses. This will always be sufficient to drive the car through snow and slush, or assist it on the track should it be derailed, and if greater force is necessary, it can be obtained from the pipe to the extent of one hundred pounds pressure, for the air chambers like the pipe will be tested to stand one hundred and twenty-five pounds. Some advantage will be had in running two cars together. Both will be filled at the engine to eighty pounds pressure. One will be allowed to do the work until its force is exhausted. By this time the motion will have increased the pressure in the other car to about ninety pounds. Then it will be allowed to propel the two until exhausted, when the first will have a pressure of perhaps forty or fifty pounds. By doubling cars and the automatic filling, it is estimated that a distance of about three miles may be covered without resorting to the ground pipe for more air.

"The advantages claimed over horses, steam, electricity or cable are considerable. The inventor claims that any line which is now in operation can be equipped with compressed air cars, air pipe line, engines and all complete for less than $7,000 per mile; that the change can be made without stopping travel for a single hour, or obstruction of the street; that once equipped, the expense of running is reduced to the minimum. No horses to buy and feed, no cable to renew, no stables to rent or stablemen to pay. The engines are so small and simple that any man competent to run a car can tend one. There is no steam to frighten horses, no disagreeable dust, no fire and no smoke; there is no tearing up streets for repairs as with the cable, and expresses and wagons can use the track as now, which can not be safely done on the cable. There are no electrical shocks during a storm, as is the case on electric roads, to frighten ladies and endanger life. With the compressed air line, there need be no change of cars to go from Fountain Square to the farthest suburban point, as is necessarily the case with the cable. Moreover, the same air that serves as a motor can be so utilized as to warm the bottom of the car, a point which certainly would be appreciated in such weather as we had last week.

"We hear that Mr. Clarke will contract to run any line of street cars and guarantee the company owning it five per cent. larger dividend on the capital stock than they are now paying. This is worth looking into.

"Here are some figures that may be interesting. A cable road will cost to build from $80,000 to $100,000 per mile. The cable must be renewed every thirteen months at a cost of $8,000 a mile. To illustrate the saving over the present system take a single line running twenty cars. The points of expense in running incurred by the compressed air line, which the horse car line would not have are, for one year:

Two engineers	$1,600
Fuel	2,000
Total	$3,600

"The horse car line will have expenses to meet not found by the air line, as follows:

Horse feed	$8,700
Horse shoeing	2,680
Horsemen	4,500
Harness	600
New horses	4,000
Total	$20,480
Total air line expenses	3,600
Difference in favor of compressed air line	$16,880

"It is presumed that other expenses, such as drivers, conductors, repairs, &c., will be equal in the two systems. It should be observed, however, that the horse car line is not charged with the continual repair of the track necessitated by the wear of the horses' feet, which the air line will not have. This and other small items will undoubtedly increase the savings to $20,000 per annum; but suppose it is only $17,000.

"From these figures some startling deductions are easily drawn. The saving amounts to about $47 per day, or $2.35 per car. In a city using three hundred cars, which is approximately the number used in Cincinnati, the saving would be $705 per day, $22,750 per month, $257,325 per year.

"The amount of additional business which must be done by a horse car line to make its profits equal those of the air line is also surprising. To make up this difference of $705 per day in running expenses, the old line must carry 17,625 passengers, at four cents each, more than the new line every day, 528,750 a month, and 6,433,125 a year. If the horse car lines of this city were paralleled by compressed air lines, they would find it difficult to compete for the trade."

Abbreviations:
SRJ, Street Railway Journal
EN, Engineering News

SRJ 5-86

New Compressed Air Motor.

A Pittsburg mechanic claims to have invented a compressed air motor for street car travel, an entirely new and economical principle. The front wheels are unusually large, and there are small air pumps, three inches stroke by three diameter, set in the periphery of the wheels. The force of the air pump is exerted by the weight of the car over the wheel, calculated at 1,000 pounds to each wheel. The air thus compressed passes into the hollow hub of the wheel, whence it carries its force into the receiver.

Compressed Air for Street Car Motors.

Mr. Norman Selfe recently read a paper on compressed air and its applications, before the Engineering Association of New South Wales, of which institution he has on two occasions been president.

Mr. Selfe introduced his subject by a reference to the comparative merits of compressed air and hydraulic appliances for the transmission of power, and pointed out that whereas the use of water was a very simple matter theoretically, the compression and expansion of air depended on the complex laws of thermo-dynamics, and that it was only through the researches of eminent scientists as Joule, Carnot, Rankine, and others that these laws were made known. Many costly experiments had been made in this colony in the past for producing cold by the compression and expansion of air that were total failures from the want of knowledge on the part of the patentees, which was now available for any student. The great and leading features to be constantly borne in mind when dealing with compressed air, are the enormous losses of power that occur during compression and subsequent re-expansion when high pressures are worked at. These losses commonly amount to about 70 per cent. of the whole power, and arise thus: First, in the compression of air the whole of the energy exerted to effect its compression is converted into heat, which raises its temperature, and therefore, its relative volume, and as a consequence, the relative power to effect the compression is increased, unless this heat is dissipated as fast as it is produced. In a good compressor, as much heat as possible is got rid of during the operation of compressing, and the remainder is dissipated through the walls of reservoirs and pipes as the compressed air returns to atmospheric temperature; so that before the air is employed to work an engine, all the power or heat that was put into it to effect the compression is practically lost. Secondly: In the expansion of compressed air against the piston of an air engine and the performance of work, the air must part with heat equivalent to the work done (and on this law all cold air refrigerating machines depend for their action), but this loss of heat brings about a diminution of volume in the air expanded in the cylinder, and a reduction in the work done. It is found that these losses not so important at low pressures as say, 20 pounds to the square inch, but at 40 pounds pressure practical results show the loss to be doubled; and at 10 atmospheres the loss is theoretically double that at two atmospheres.

In order to place this part of the subject clearly before the meeting, Mr. Selfe exhibited three large tables which he had compiled from the most eminent authorities, and which showed at a glance, both from theory and practice, the necessity of avoiding [illegible] pressure if any economy of power is sought in working with compressed air. After the introduction, the subject was divided into three parts, dealing respectively with the historical or past and present use of compressed air, the principles involved in its use, and some recent improvements in its application. The first part showed that compressed air had been applied as a motive power on tramways as long ago as 1839, and that its use had gradually extended until at the present time there were several systems actually and successfully in use, the principal one of which is that of M. Megarski. This compressed air-tram system has been in operation in Nantes since 1879; it has been most favorably reported on by English engineers, and is now running at Holloway, in North London. Megarski uses air at 450 less per square inch, Colonel Beaumont at 1,000, some American engineers 3,000 lb., and, as they all seek to carry sufficient stored up air in their receivers to go for long distances, these receivers are enormously heavy, and the greater part of the power given out is employed to draw the machinery, and only a small percentage is available for the traction of the passengers. Again, owing to the great pressures, the power dissipated as heat is so large that artificial warming apparatus is used on the tram engines to keep the whole thing from freezing. The second part of the paper dealt exhaustively with these losses, and showed to what extent and why they were inseparable from the systems hitherto in use, and here another table showed the loss of power which resulted from carrying compressed air through pipes. Great experience has been gained in the Alpine tunnels of Mont Cenis and St. Gothard. The latter is 14,920 metres long, and it is found that with air at 120 lb. pressure, 120 horse power could be conveyed a mile through a six inch pipe with a loss approximately of only 5 per cent.; with larger pipes the loss of course is proportionately less.

The third part of the paper was really the most important, for here, by means of large diagrams and illustrations, Mr. Selfe showed how, by an invention of Mr. Pardy in America, it is possible for tramway cars to be driven with a very low comparative pressure of air and thus avoid the enormous loss of efficiency that attends other systems, while at the same time the greater part of the weight of the machinery is done away with. This is effected by laying an air main in the street or road the same as a water or gas main, with suitable valves at intervals, so that by means of a nozzle and flexible tube, the driver of the tramcar can replenish his reservoirs with air whenever he stops to put down or take up passengers. In actual practice it was found a car could be charged in a few seconds.

Mr. Selfe then compared the Pardy system with that of Mr. Megarski, the most successful one yet running, and here we quote the paper in full.

"In order to make a comparison between the merits of Mr. Pardy's tramway improvements and the systems before in use with compressed air, I will take that of Megarski, first because that appears to be best known, and secondly, because up to the present it has had the largest measure of success. Sir F. J. Bramwell examined into and reported on the Megarski system at Nantes, in France, after it had been in regular work for three and a-half years, and he read a very favorable account of it before the Mechanics' Section of the British Association at the Southampton meeting in 1882. It appears that the fuel used for the compressing machinery at Nantes amounted to 1.74 lb. of coal per ton gross of the car weight per mile run, whereas Merryweather's engine did a ton mile with 69 lbs. of coal. And drawing conclusions from this, Mr. D. K. Clark, in his last volume on tramways, says, 'while such a contrast can be maintained it needs but little argument to prove that the direct steam-powered tramway engine is, as it ought to be, the more economical.' Now, I am bold enough to differ with Mr. Clark, for the simple reason that coal consumption is only one factor out of many in estimating the economy of a tramway, and if the cost of motive power was the same in both cases there would still be no reason why the permanent way should have the extra wear and tear of carrying the boilers and fuel when they could be left stationary, but the comfort of the passengers, the absence of smoke, smell and steam are all points affecting the economy of the working. Suppose now, however, we make the contrast under the fresh light let in by Mr. Pardy. The Megarski cars, built for the Caledonian road service of the North Metropolitan Tramway Company, London, carry 40 passengers, have their reservoirs strong enough to carry a pressure of 450 lbs. and weigh from 6½ to 7 tons empty, or, say, 9 to 9½ tons loaded. A low pressure car of about the same dimensions and as shown on figures 1, 2, and 3 to carry, say, 110 lb. pressure, will not require reservoirs of more than one-third the weight of those that carry 450 lb., and the hot water vessels, with the contained water, will be dispensed with altogether. The car on the Pardy system, can thus be reduced in weight to about four tons empty, and say 6½ tons loaded. That is to say, about 70 per cent. of the weight of the high pressure Megarski car at nine tons loaded, and a little over 60 per cent. when lightly loaded. The maximum pressure in the low pressure reservoirs will be nine atmospheres total, and the engines will work at from 15 lb. to 30 lb. above the atmosphere,

instead of being used at from 75 to 90 lbs., as in the Megarski car, and from what has already been shown as per table B, about the larger relative efficiency when working with low pressure air, an ultimate efficiency of 40 per cent. should be attained in the low pressure, as against 30 per cent. in the high pressure car. That is to say, the efficiency in the Megarski system is, probably, only 75 per cent. of what may fairly be expected from a low pressure one. As the relative weights are taken as 70 per cent. fully loaded, and 60 per cent. light, a mean esiimate of 65 per cent. is fair for the proportion of the low pressure to the high pressure car; and the relative power required for the same weight being 75 per cent., the actual power becomes 75 × 65—100, which gives 48.75 per cent., or less than one half of the power for the low pressure car of what is required with the higher pressure one."

The writer then shows that hitherto the great aim of designers of air tramway systems has been to go the maximum distance with a charge of air, and thus the pressures and dead weight have been increased while the efficiency as regards the power employed has got very low— in fact, so as to use from two to three times the fuel of steam locomotives. But with the introduction of an air main along the route the whole conditions are changed. The paper goes on to say:—"If large compressing engines of 500 horse power were erected in a favorable situation for getting coal and condensing water they should obtain an efficiency as prime movers at least twice as good as the present tramway locomotives, and with air cars there should not and need not be more than one-half of the present average dead weight per passenger to put in motion. In such a case the same work in passengers carried, could be done with the same fuel as is burnt now, if the ultimate efficiency of the air engines on the cars was only 25 per cent. of the initial power, that is, if 75 per cent. were lost. For reasons already pointed out, however, a much higher efficiency than this 25 per cent. should result with the low pressure. But surely if the coal bill was 20 per cent. greater than now instead of less, it would be warranted by the gain in comfort, convenience, and cleanliness, in the absence of steam, smell, and smoke, and running of light, handy and smart cars at much more frequent intervals, and in the reduced wear and tear of permanent way that would result from the substitution of compressed air cars in place of lumbering roadway destroyers, with their enormous loads, inconveniences, and dirt *ad nauseam*." Mr. Selfe refers to a proposal made to supply compressed air in Birmingham as water is supplied in London, Hull, and other cities, and shows that there are so many obvious advantages, especially for domestic motors, in having air, its ventilating and refrigerating properties when it has done its work especially being desirable.

Mr. Selfe winds up his long and exhaustive paper with a comparison between the cable system, the steam locomotive system in use at present in Sydney, and the low pressure pneumatic system, and here exhibited large sections of the six principal roads of San Francisco drawn to the same scale as the six principal tram routes of Sydney, to show that the different grades in the two cities make the conditions altogether different for traction. Comparing these three systems with one another Mr. Selfe concludes thus: Comparison of Three Systems of Tramway Propulsion.—The rival systems of motive power for tramways most likely to be brought into competition with the low pressure pneumatic system that I have attempted to explain this evening, are: First, the cable roads as so successful in San Francisco; and, secondly, our present steam locomotive arrangements. A great deal is often heard about the cable roads of San Francisco, and it has been put forward that they are just the thing for the requirements of Sydney. I know this city well, and I have had every opportunity of becoming acquainted with the tramway system in the capital of the Golden State, both by observation and description; the result is, that I yield to no one in my admiration of the skill and ingenuity of the engineers, as well as of the enterprise and foresight of the capitalists, that have led to their mechanical and financial success; but Sydney is not San Francisco, and the conditions that apply to tramways in these two queen cities of the Pacific are altogether different. Firstly, the cable roads in San Francisco have grades as steep as one in five or six, to work up which no ordinary locomotive, whether air or steam propelled, would be suitable. The six principal cable roads rise over hills from 250 to 300 feet high, and in several cases pass over two such hills in their run. The latest road up Telegraph Hill is, I believe, about one in three, and only wants tilting a little more when it would not be a tram-road at all, but an elevator, and for such conditions as these I know of no system so suitable as the cable; but although Sydney is a hilly city, as cities go, we have no grades on our tram roads that locomotives cannot climb, and thus the first motive for a cable road does not exist. Secondly, the cost of cable roads is very great in construction, maintenance, and working expenses. This in itself would not be an objection if there was a probability of the earnings being commensurate; but it is not likely to be so, for in San Francisco the conditions do not present as they do here in Sydney seven or eight suburban tram lines, all converging to one focus at Liverpool street, and then, figuratively speaking, running strangled down a side street, to a terminus in a back yard nowhere. It is unfortunately the fact that through the physical configuration of Sydney something like that is the case here. There in San Francisco the streets are straight, and each separate cable road has its terminus in a populous center of city traffic, and it runs out through main streets which correspond to our George, Pitt, York, King, and Park streets, but on a much larger scale. The tram lines there command also separate avenues of intramural traffic, such, for instance, as is carried in Sydney by the railway omnibuses, and they also perform the greater part of the work that is here done by the suburban railway. There is thus an enormous traffic, and one much more uniform throughout the day than we have here, owing to so many of their leading business streets being traversed by the tramways. Thirdly, it has been estimated in San Francisco that cable roads cost at least five times as much to construct as tramways and three times as much as a road and air main for the pneumatic tramway. In the case of the cable it is in constant motion, with its supporting pulleys, and wear and tear is going on whether one car an hour or one car per minute is the service on the tracks. With an air main there is no wear and tear proper, and no more depreciation than belongs to an ordinary gas or water main. Fourthly, the cable roads consume a large portion of the power exerted to work their own destruction in the wear and tear of cable, which constitutes such a large proportion of the dead weight or non-payable load.

In an able paper on the cable roads of San Francisco, read by Mr. Hauscom before the Technical Society of the Pacific Coast, the average working of seven principal cable roads is summarised thus:—Out of the total power exerted by the engines, 68 per cent. goes to move the machinery and cable, 28 per cent to draw the cars, and 4 per cent. only to carry the passengers. If you give any consideration to these four points in the cable system that I have just referred to, I think you must, as I do, conclude that the conditions for its successful adoption in Sydney do not exist, and so we will next proceed to consider the system we actually have in use. Under existing arrangements here in Sydney we commonly have a 16 ton locomotive drawing two cars of a weight aggregating eight tons, and sometimes 10 tons, or collectively, say, 24 tons of dead weight in a train. And although for an hour or two at morning and evening the cars may be crowded, yet on many lines the average throughout the day is said to be only about 20 passengers. As a basis of comparison, and to give our present system every chance. I will take 45 passengers instead of 20 as the average load, then at 15 persons to the ton, the live load will be 3 tons, which, added to the 24 tons dead weight, makes the total load 27 tons. That

is to say, make the best of it, and then only 11 per cent. of the power is exerted to move the passengers, and 89 per cent. is required to drag the dead load about, and destroy the permanent way. Lastly, under the pneumatic system, where light cars at frequent intervals are proposed, I take for comparison a London metropolitan horse car for 40 passengers, which weighs 2½ tons: if to this is added one ton of reservoirs, etc., and half a ton of engines, etc., the weight ready for work becomes 4 tons. Assume it to be only half loaded or with 20 passengers at 17 cwt. (I have taken 45 for present system, remember), the total running weight would be 107 cwt. Of this gross load the 27 cwt. of passengers would be just over 25 per cent. instead of being only 11 per cent. as in the present system with 45 passengers; but if we consider the air car as fully loaded, or with another 27 cwt., making a total of 6 tons 14 cwt., then the proportion of useful effect or payable load rises to over 40 per cent. The light air cars can be started every half hour, every ten minutes, or every minute, according to the requirements of the traffic; and if they are made to carry no roof passengers they can be managed with only one man to drive and collect fares, as is done with the bob-tail cars used in some cities. Looking at all these points, I think no hesitation can exist as to the advantages of air cars over our present system.

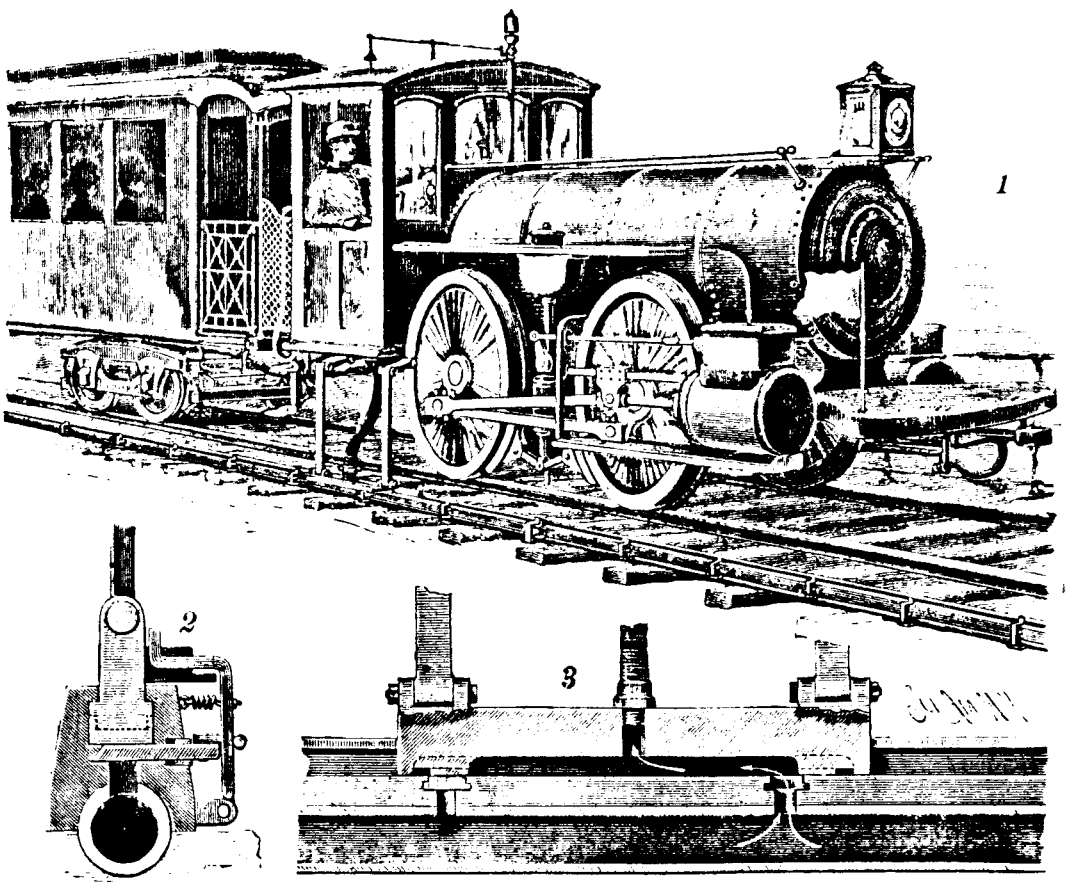
Scientific American.

1890.
P. 250

IMPROVED MEANS OF DISTRIBUTING POWER.

A means of conveying steam or compressed air along a line of road, to be delivered to a motor propelled thereon, is illustrated herewith, and forms the subject of a patent issued to Mr. Victor H. Tomlinson, of Hudson, Col. Fig. 3 is a central longitudinal sectional view of a section of the apparatus, Fig. 2 being a cross sectional view. In the upper face of the pipe or tube to which the motive agent is delivered from a central station are castings with undercut grooves, the castings being arranged end to end throughout the length of the tube, and having ports registering with ports in the tube. Within the undercut groove of the casting is a receiver with grooves to receive any proper packing, the receiver having a flexible pipe leading to the steam chest of the motor or a reservoir carried thereby. The receiver is held to the motor by upwardly extending standards, and as the receiver is forced forward by the onward movement of the motor, a forward valve is opened as another at the rear is closed.

The ports in the pipe at the side of the track are controlled by valves engaged by spring-pressed levers, and a pipe leads to the steam chest of the motor, or the reservoir carried thereby, the distance between the ports being about equal to the receiver recess. The way to this recess from the pipe at the side of the track is opened by a lever as the motor moves forward, one of the valves being opened as another at the rear is closed. The economy of this system of supplying power will be readily appreciated when it is considered that steam can be generated or air compressed at a central station at a rate usually not more than two-fifths of the cost of generating such power on an independent traveling motor. The cleanliness of such a system, and the absence of noise, would also form striking advantages in favor of its adoption for the propelling of street cars, while its cost need not necessarily be higher than that of cable traction or electricity.



TOMLINSON'S APPARATUS FOR SUPPLYING COMPRESSED AIR TO LOCOMOTIVES.

Scientific American.

APRIL 5, 1890.

Compressed Air Cars.

Messrs. Hughes & Lancaster, whose works are at Chester, England, have been for some time steadily working to improve the low pressure compressed air system which they have introduced. *Engineering* says they have taken one of the ordinary Chester horse cars, and by means of a certain amount of cutting and contriving have managed to produce a fair example of their invention, at any rate sufficient to give a working example of the device. Underneath the car cylindrical reservoirs have been placed and a motor has been introduced. In other respects the vehicle has not been altered to any noticeable extent—in fact, it is only on close inspection that one realizes that the car carries its own motive power. The reservoirs contained air compressed to a tension of about 170 pounds to the square inch, at least that is the initial pressure when the car is first started after having been charged; but as the total storage capacity of the car in question is but 50 cubic feet, it will be easily understood that the pressure falls with considerable rapidity as the journey is made, more especially if the car has to climb a fairly steep gradient, as was the case during some runs we recently made. It may be as well to state at once that there is ample space under seats and elsewhere to place other cylinders, so as to very greatly increase the storage capacity.

The motor on this car is a Rigg engine, but unfortunately this has not been found so far very suitable for the conditions of driving tramcars. At any rate the leakage is very great, as was shown by the way the pressure gauge fell when the car was standing.

As the car will travel but a short distance—we believe about two miles on the level—upon its initial store of energy, special arrangements have to be made to recharge the storage cylinders. To effect this there is an air-compressing plant erected at a central station, and this supplies an air main which is laid along the entire route. At convenient intervals, greater or less according to the gradient and storage capacity of the car—probably two miles would be the maximum distance of any two from each other—there are special valves attached to the main. These are placed in pits close to the outside of one rail, the pits being covered by iron lids level with the roadway and causing no obstruction to traffic. The car has to lift this lid in order that connection may be made between the air reservoirs of the car and the supply pipes. In order to perform this opening operation, there is a bent lever on the lower part of the car.

When it is required to recharge the reservoirs, the lever is lowered by the attendant and the lid is raised; there is a stud on the end of each arm of the car valve. As the car passes on, it causes the car valve to make a quarter turn on its center, that center being the end of the air pipe in connection with the reservoirs. The valves are brought into their open positions, and air flows freely from the street main to the car reservoirs. When the latter are charged the car is started, both valves make a part of a revolution, until they are brought to the closed position, and the operation is completed by the lid of the pit closing by its own weight.

The attendant having gone through the extremely simple operations of lowering the lever, the rest of the operations are purely automatic, and the practical success of the device naturally greatly depends on the rapidity with which the reservoirs are charged. In the car we have described, to raise the reservoir pressure from 60 pounds to 165 pounds per square inch took ten seconds, or about one-sixth the time generally required to get an elderly lady or stout gentleman off the pavement on the footboard.

We had recently an opportunity of inspecting at Chester this car and the air main connections, through the courtesy of Professor Henry Robinson, M. Inst. C.E., who is consulting engineer to the promoters of the system. The short runs we made were conducted without a hitch, and enough was shown to prove that this system is quite practicable in its working, and that many of the objections to a steam motor are entirely absent.

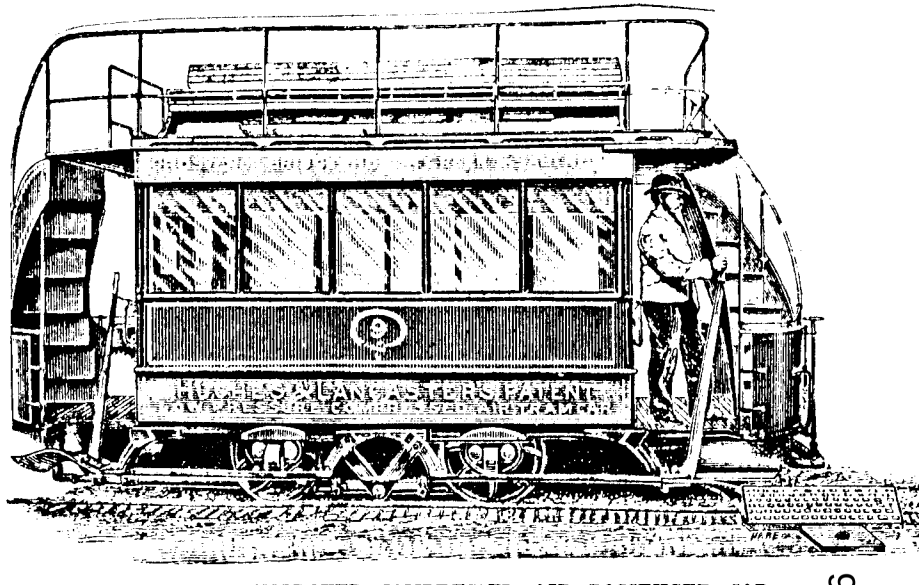
The total weight of the car and machinery is 3 tons 14 cwt., and the resistance has been estimated at not less than 27 pounds per ton by Professor W. C. Unwin, who made some trials with this car.

Scientific American.

APRIL 12, 1890.

COMPRESSED AIR PASSENGER CARS.

The use of compressed air as a motor power for street cars has heretofore not proved commercially successful, owing chiefly to the very high pressure employed. These conditions entailed a great addition to the amount of dead weight that had to be moved. We need hardly point out that the loss in compressing air increases rapidly, the higher the pressure goes. In the systems to which we refer, the stored pressure varied from 450 pounds to 1,500 pounds per square inch, although a pressure of but little over 10 pounds was sufficient to propel the car. To further spin out the air supply, heating apparatus was applied, involving a still further load of dead weight. These arrangements necessitated the use of a separate locomotive, or an addition to the car equivalent to a separate locomotive, besides entailing the excessive cost of compressing the air to such high pressures. With these drawbacks it is not surprising that the application of compressed air in this manner did not work out with satisfactory economy in actual practice. We have, however, recently investigated the working of a highly ingenious system of tram car propulsion by means of compressed air, which promises to solve the problem. This is Hughes & Lancaster's low pressure compressed air system, which we have had the opportunity



IMPROVED COMPRESSED AIR PASSENGER CAR.

of examining at Chester. In this system the motive power is compressed air stored in the car itself at the comparatively low pressure of from 150 to 170 pounds. The air reservoirs on the car, when exhausted, can be recharged with a fresh supply of compressed air automatically, at frequent points along the route. The motor, which is one of Rigg's rotary engines, is also carried on the car, thereby avoiding the necessity of a separate locomotive engine. The car moves along without any visible agency, the machinery being all covered in and out of sight underneath it. The air need only be compressed to one-third or even one-tenth of the pressure previously used, and is stored in light receivers which can be made to form portions of the main framework of the car itself.

In carrying out this system, a compressed air pipe is laid under the road or footway along the tram route, and is kept charged with compressed air by means of air compressors at a central depot, and branches are led off at suitable points to valves fixed under the roadway, close to the tram rail. Each valve is inclosed in an iron box, covered with a lid level with the roadway, like an ordinary street manhole cover. A short piece of grooved rail, about 15 or 20 feet long, is laid alongside the tram rail at each side of the box. When the driver wishes to take up a fresh charge of air, on approaching one of these valve boxes he lowers a plow-shaped scoop into the groove, the point of which inserts itself under the front edge of the lid, which it gradually turns back upon its hinges, as the car moves along, until full open. This arrangement will be seen on reference to our engraving, which shows the tram car we recently saw tried at Chester. The car being then over the open valve box, a valve which is carried on the horn plate is free to engage with the valve in the street box. The car valve is guided into the right position for passing on to the arm of the street valve by means of a projection which passes into a guide formed on the inside of the cover. The car valve is double-ended, so that one end is always left in position for entering, whatever direction the car may be going, and the street valve is provided with four arms, so that it is always left with its arms at the right entering angle for either direction when the car leaves it. As soon as the car passes clear of the valve box, the lid closes of itself, leaving the roadway free from any obstruction. Generally the passage of the car through the recharging valve at reduced speed suffices to refill the receivers with pressure sufficient to carry on to the next recharging valve, but the driver may pull up at the valve, and stand until the full pressure is reached, which occupies but a very few seconds. On single lines the street valves would be placed at the passing places where the cars frequently have to stop, and in all cases at the regular stopping places. On heavy gradients street valves would be placed at the passing places where the cars frequently have to stop, and in all cases at the regular stopping places. On heavy gradients the street valves would be placed at more frequent intervals than on the level. It is these arrangements, exceedingly simple and effective as they have been proved to be in actual practice, which enable the car to be worked with low pressure air, and the separate locomotive and heavy receivers to be dispensed with.

We append the particulars of a careful series of experiments made by Professor Unwin, F.R.S., on the Chester tramways with the Hughes & Lancaster system, to ascertain the consumption of air on the different inclines. Some of the trials were made during wet, greasy weather, and the results necessarily varied from sundry other causes, such as interruptions, unexpected stoppages and startings, etc. The foot pounds of work done per pound of air used were found to vary from 5,456 foot pounds to 28,048 foot pounds, including all losses from leakage, etc. Taking 14,000 foot pounds as a fair average, and calculating the consumption of air on the Chester line as a representative one, upon this basis, we have the following results for the cost of motive power: Weight of 28 passenger car, including engine, air receivers, and full load of passengers=5 tons 9 cwt. Length of line=3 miles nearly. Gradient varying from 0 up to 1 in 18·5. Consumption of free air—Outward journey 1,984 cubic feet, return journey 2,523 cubic feet=2,255 cubic feet free air average per journey. Say 2,300 cubic feet free air on the average run. Car ran 309 yards up City Road incline in 1 minute 10 seconds=a speed of 9 miles per hour. Average duration of journey one way=say 20 minutes on consumption of 2,300 cubic feet of free air. The air will be compressed to 170 pounds to insure the rapid filling of the car receivers up to 150 pounds. Power required to compress 1 cubic foot of free air to 170 pounds above atmospheric pressure in full adiabatic compression, including engine friction, leakage, clearances, etc.=9,800 foot pounds; 9,800×2,300=22,540,000 foot pounds to compress the whole volume of air used during the 20 minutes' run: 22,540,000÷20=1,127,000 foot pounds=34 gross horse power at central compressing station for one car. Coal consumption=say 3 pounds per horse power per hour=102 pounds, or say 1 cwt. per hour, say at 10s. per ton, or at 6d. per cwt.=6d. per hour, *i. e.*, for 9 miles. Hence cost of fuel=⅔d. per car mile. With triple expansion compressing engines consuming 1½ pounds coal per horse power per hour, the cost would of course be only ⅓d. per car mile.

The Mekarski Compressed-Air Tramway Motor.

Among the "Reports of Consuls of the United States," for February, 1890, is one of more than usual engineering interest from Consul-General RATHBONE, of Paris. This is a report on the operation of the compressed-air tramway motor, on the Mékarski system, which has been in operation near Paris for over two years, and in the city of Nantes for a much longer period. While we have already described this system in ENGINEERING NEWS of May 12, 1888, the present report is so much more complete that we give it in full, as follows:

The advantages enumerated are:

(1) The motor does not emit smoke or hot gases, and is almost noiseless.

(2) A greater speed is attained than with horses where necessary.

(3) A special track or overhead appliance is unnecessary.

(4) Being very light, it can be easily handled on steep grades.

(5) Simple in form, it does not frighten horses; the machinery on the front platform is almost invisible from outside.

(6) A possible explosion of air reservoirs is less dangerous than of steam or superheated water.

(7) Maintenance in repair is very simple.

(8) Only one person is necessary for managing the machinery, and he is not necessarily a skilled engineer.

(9) In crowded days or times of day the number of passenger places may be easily augmented by the addition of one or even two tenders or ordinary cars, without a motor, thus making a short train.

The principle of the system is very simple. Air is compressed to 40 or 45 atmospheres; the reservoirs of the motor are charged at this pressure; the air to be used is reduced to a pressure of 5 to 10 atmospheres, and at the same time heated to a high temperature and charged with moisture in a vessel called the heater (*vouillotte*); from there it passes to a double expansion engine, where it acts like steam in moving a piston rod.

The running expense of this motor per kilometre has proved:

	Francs.
Charging and running	0.2079
Depreciation of machinery	0.1233
Depreciation of car	0.236
Total	0.3076

This is 6 cents per kil., or 9¼ cents per mile. Including all expenses, interest on track, etc., the cost of each car making 84 kilos. per day is 52.92 francs. The cost per day of a Paris omnibus in the same way is 106.57 francs, but the omnibus runs 90.7 kilos. and seats 50 people. Since the Mékarski tram car seats only 38 people, the proportionate expense for the same distance and the same number of people would be

$$52.92 \times \frac{90.7}{84} \times \frac{50}{38} = 75.18 \text{ francs.}$$

Therefore, the saving in this tram system is nearly 30 per cent.

The cost of the different parts of the Nogentais tramway is as follows:

	Francs.	
Automobile	16,000 =	$3,200
Extra or tender cars	12,000 =	2,400
Reservoirs for accumulation, containing 1,250 liters	1,250 =	250
Compression pumps and engines	17,500 =	3,500
Tubular boilers, 30 sq. meters surface, 327 sq. ft.	8,000 =	1,600

The weight of tram is, when empty, 7,500 kilos. (8¼ tons) and 10,300 kilos. (11⅓ tons) with 40 passengers.

The co-efficient of friction, ordinarily 17 to 12% on tramways, goes occasionally down as low as 10%, or even 8%. However, by the use of sand, for which there is an arrangement, a friction of 15% can always be depended upon. The steepest grades on the line are 0.045 and 0.052 At one place the grade is 0.017 on an average for 870 ft. These steep grades are only justified by the absolute impossibility of changing the profile of the streets themselves. The minimum radius of curvature on the line is 40 meters (133 ft). The car is designed to go round a curve of 35 meters (116 ft), however, without difficulty.

The resistance on such heavy grades, allowing for both friction and inclination, is 55 kilos. per 1,000 (110 lbs per ton). An empty motor can therefore draw up this incline—

$$\frac{7.500 \times .15}{.055} = 20{,}500 \text{ kilos.}$$

that is, 20,500 — 7,500 = 13,000 kilos. besides itself. In other words, it is capable, easily, of drawing two extra carriages of 6,000 kilos. (6⅓ tons) gross weight each. If the motor is full, the extra friction will admit of its drawing proportionately more—15 tons at least. This doubling or tripling the carrying capacity is very advantageous, because it does not add to the number of employés working, and very little more air is consumed. Below is shown the amount of air used per unit of distance:

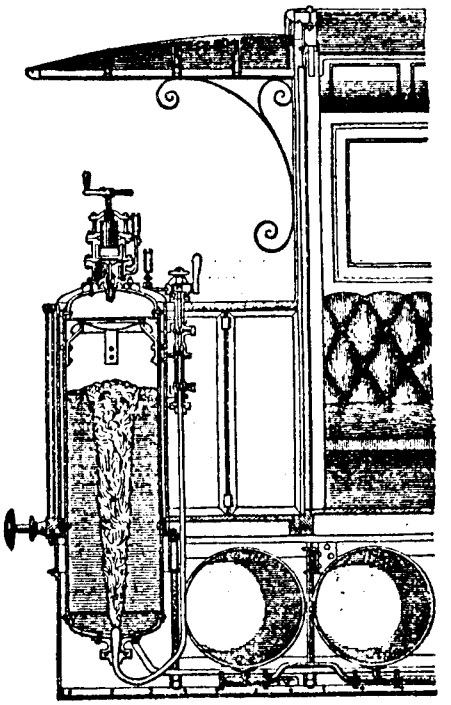


Fig. 1. Front Platform, showing Heater.

The reservoirs of compressed air are separated in two sections—the battery and the reserve; on leaving the station both of these are charged with a pressure of about 40 kilos. per sq. centimeter (40 atmospheres). After the complete run, that is, 12 kilos., the pressure of the battery is diminished by 26 atmospheres, and that of the reserve by 8. As each atmosphere of pressure corresponds to 2.5 kilos. of air in the battery, and to 0.8 in the reserve, the total weight of air used is $26 \times 2.5 + 8 \times .8 = 71.4$ kilos., or about 6 kilos. of air per kilo. (21 lbs. per mile). With an additional carriage in connection, it has been found that only 1.5 kilos. per kilo. (5¼ lbs. per mile) extra is required. Thus, in doubling the number of places the loss of air is raised only 25 per cent.

In comparing this system with the alternative of an ordinary small-sized steam locomotive, M. Mékarski shows that in an ordinary economical locomotive 2.5 kilos. (5.5 lbs.) of coal are used per horse-power; also that the proportion of work to force generated in a compressed air motor ought to be at least 40 per cent., in order that it shall be as economical as a steam locomotive. This state of affairs could be realized by using a stationary engine using 1 kilo. (2.2 lbs.) of coal per horse-power, an object easily attained.

To compress 1 kilo. of air in a reservoir at a pressure of 50 atmospheres, theoretically 62,400 kilogram meters are used if the compression is adiabatic, or 32,950 if it is iso-

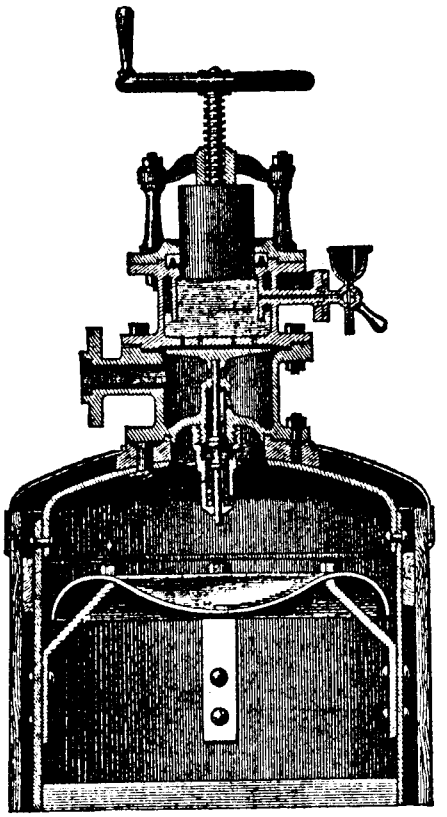


Fig. 2.—Pressure Regulator.

thermal. Practically, the operation is effected at intermediate conditions, and needs about 48,000 kilogram meters of work. The lost work in this operation may be calculated at 25 per cent. of this, or at 12,000 kilogram-meters, making the total work necessary 60,000. On the other hand, 1 kilogram. of air at a pressure of 10 atmospheres, the pressure at which the air is used, occupies a volume of 119 liters (31.44 galls.), and can furnish, with an expansion of 6 volumes, a force of 28,900 kilogram meters. Reducing this to 24,000 to allow for lost work, it is seen that the available work is $\frac{24000}{60000}$, or 40per cent.

In this calculation the pressures are somewhat higher than are used in the tram-cars, for it was made in designing a larger motor; nevertheless, the proportion of pressures remains the same, and the result compares exactly with the practical results shown in working the tramway at Vincennes.

It might be added that the coal used for the large stationary engine is of a very inferior quality and price to that ordinarily used in small locomotives used for the same purpose, and that they, in their turn, use more coal in comparison to their power than is used in regular railroad service. The high pressure at which the air reservoirs of the "automobile" are charged is the result of the necessity to compress a sufficient weight of air in a moderate compass.

As regards the carriage or passenger par t of the car this is exactly similar to all French tram-cars, having an interior part and an upper part, or "imperial." This carriage is 8 meters (26 ft. 3 ins.) long by 2.1 meters (6 ft. 11 ins.) wide. The steps at the back are arranged to make a connection with the extra car when attached, There is also here a pipe connecting with air brakes in the last car

Parallel to the axles of the wheels of the tram are placed the air reservoirs, nine in number, divided into two groups intended to carry the compressed air. These are made of steel 12 millimeters (one-half inch) thick, and are tested for 60 atmospheres. The first of these two groups is composed of six reservoirs, having a total volume of 2,030 liters (536¼ galls.); the second group of the remaining three reservoirs, called the reserve, contains 1,066 liters (281½ galls.); the total capacity, therefore, is 3,106 liters (817¾ galls.) This volume of air at 45 atmospheres weighs 170 kilos. or 380 lbs. The battery and the battery and the reserve are made independent, in order that the reserve may always be kept at high pressure, so that an extra powerful effort may be given to the engines in case of need, even at the end of the trip. The different reservoirs of each group are connected by a strong and permanent system ot piping. Both groups send their air by pipes to the lower part of an apparatus called the heater. This apparatus is the most characteristic of the Mékarski system; and the need of some such appliance will be directly seen from the following calculation:

In considering the expansion of a gas, the proportion of the volumes before and after expansion being $\frac{V_0}{V_1}$, and the initial temperature being t_0, the temperature at the end of the expansion is

$$\frac{273 + t_1}{273 + t_0} = \left(\frac{V_0}{V_1}\right)^{.41}$$

In the present case $\frac{V_0}{V_1}$ being one-sixth, we find

$$\frac{273 + t_1}{273 + t_0} = .48.$$

If, by example, air is introduced in the cylinders at the temperature of 15° C. (59° F.), it would go out theoretically at −135° C. (−211° F.). Outside of the necessity of preventing the moist ire in the expanding air from freezing up the cylinder-valves, etc., we find it advantageous to have the initial temperature as high as possible. For the work done is given by the expression

$$Tm = (273 + t_0)\ [29.28\ (1 - \frac{P^1}{K P_0}) + 73.3\ (1 - K^{.41})\ ]$$

In this expression, Tm is the work effected, t_0 the initial temperature in degrees Centigrade, P^1 the resisting pressure, P_0 the initial pressure and K is the proportion $\frac{V_0}{V_1}$. Therefore $(273 + t_0)$, or, in other words, the absolute temperature should be made as large as possible.

If the value for which the temperature of the escaping air is to be 15° C. (59° F), it is found that the initial temperature should be 327° C. (620° F.), as calculated for theoretically dry air. To avoid any such inconvenience in using air at such a high temperature, and also the necessity in such a case of having some sort of a furnace, the principle in this system is to saturate the air with moisture at a much lower temperature, taking this moisture from the hot water inside the "heater." The vapor in the air during the expansion is partially condensed, and this part, giving up its latent heat to the air, acts to greatly moderate the decrease in temperature.

The heater (see Fig. 1) is in form a cylindrical reservoir placed vertically on the forward platform of the train. It also is made of steel, and contains 200 liters (53 galls.) of water under pressure and at a temperature at the outset of 155° C. (311° F.). The air passes through the water in the heater in bubbles and becomes heated, and at the same time saturated with water. It collects here in the top part of this cylinder, which serves in the machine the purpose of a steam dome in a boiler. This part contains a curved piece of sheet-iron which forms a sort of splasher.

The regulator of the pressure ("détendeur," see Fig. 2) which the engineer manœuvers to change the pressure of the air going to the cylinders, is on top of the heater. It is a very ingenious apparatus serving to expand the air to the pressure from which it is found in the reservoirs to that at which it is to be used in the cylinders. This pressure, normally 4 or 5 atmospheres, on up grades is sometimes increased to 15, and on down grades reduced to nothing, the supply cut off, and the tram left entirely to run by gravity. This regulator is composed of two brass chambers superposed and separated by a rubber diaphragm. The first forms a hydraulic press, in which a piston descending compresses water in an annular space where a small quantity of air is confined. This cushion of air is compressed and plays the part of a spring, by which the necessary tension is easily given to the water.

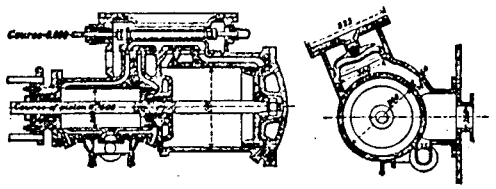
[*To be continued.*]

The Mekarski Compressed-Air Tramway Motor.

(Continued.)

The air, being heated and saturated, to pass to the cylinders goes through an orifice of the lower chamber of the regulator in which a conical valve plays. This valve is arranged in such a way that it closes by the effect of the pressure of the air in the heater. It only opens when a pressure is made on its upper face acting on the diaphragm of the little hydraulic press. It is seen that the first effect of the pressure in the hydraulic press is to open the valve and admit air. As soon as the pressure in the lower chamber gets to be as great as that in the upper, the pressures on the two sides of the diaphragm being equal, the valve closes by the pressure from below. This common pressure, which can be so easily regulated, is the pressure fed to the cylinders. This pressure, which remains automatically constant as long as the wheel moving the press is untouched, can be varied at will.

The air now passes to the cylinders, which are arranged in sets of two, each pair forming a tandem double expansion engine. The two cylinders of a set are of different diameters and are cast in one piece. The rod of the two pistons passes through the cylinder head in a spring metallic stuffing-box. The air is admitted to both cylinders in succession by the means of the same compound slide-valve. The admission to the smaller cylinder is cut off at about two-thirds the stroke. This air is now passed into the larger cylinder, whose volume is four times larger than the first. The total proportion of expansion, therefore, is about 6 volumes. Such an expansion cannot be produced with the steam in locomotives, especially where great promptitude in starting is required. Both factors governing the tractive power can be changed—the cut-off, and the pressure of air— and consequently this system is one that can be most perfectly controlled. Since, however rom this large expansion it might result that with an initial pressure and cut-off the expansion would be to a pressure less than 1 atmosphere, and a negative work would ensue, there has been placed at the lower part of the cylinder an air-valve allowing outside air to enter in such an emergency.



LONGITUDINAL SECTION. CROSS SECTION.

Figs. 3 and 4.—Sections of Cylinder.

Figs. 3, 4 show a cylinder rather larger than the one in use on this tram-way, designed for a full-sized locomotive. It, however, shows the proper proportion and arrangement of the parts. The speed, so easily varied, can be made as much as 65 kilos. (40 miles) an hour if necessary. The legal limit of speed on the tram-way is 20 kilos (12½ miles).

The arrangement of the machine, in which the space nside the wheels and under the car is entirely taken up by the reservoirs, obliges the cylinders and their dependent parts to be placed outside. Their protection, however, is insured by a sheet-iron boxing, which, with its closed doors, conceals every thing under the car. In order that no difficulty in cold weather from the collecting and freezing of the moisture in the air may take place, the air is led from the exhaust valves of the cylinder by a pipe out of the box and under the car. So far the coldest weather has not had any disagreeable result in any part of the machinery.

The engineer is placed on the front platform of the tram, which is railed off from the public, and manages the regulator. Two manometers are placed on top of the heater, and indicate the pressures in the battery and the reserve. A third manometer gives him the pressure in the regulator and the cylinders. All the motions of manœuvering the machine are extremely simple: there is a lever to change the action of the slide-valve, thus giving more or less cut-off or changing the direction of the motion; there is a lever to apply the air-brakes; another to cut off the supply of air to the cylinders, and a small cylinder in which, when the piston is pressed down, the escaping air sounds a horn.

The two pairs of wheels are coupled by a connecting rod; thus both act as drivers, and the whole weight of the car is made use of in propelling itself. The axles being only 1.6 meters (5 ft. 3¼ ins.) apart, they allow the car to go around the shortest curves without difficulty.

The tram, when charged with air, could make on an ordinary grading a run of over 20 kilos. (12½ miles) without recharging, but on this track only 14 kilos. (9 miles) can be made, on account of the heavy grades and the unusual obstructions in the way of dirt, etc. The mean consumption of air on this line is about 10 kilos. per kilo. (35 lbs. per mile) where the grade is the heaviest; where the grade is only 0.02 only 7 kilos. per kilo. (24 lbs. per mile) are necessary.

The machinery and apparatus for compressing the air is in two sections at two different stations, the larger at La Maltournée, and the other at Vincennes. The station at La Maltournée has—

Two tubular boilers of 60 meters (653½ sq. ft.) heating surface apiece in the boiler house.

In the engine room, four 35 horse-power steam-engines, each working a large air compressor.

A reservoir room containing twelve reservoirs of air at 45 atmospheres of 1,250 liters (330.2 galls.) capacity and intended to contain the air compressed by the pumps in the intervals between the charging of the cars.

Reservoirs of water and a feeding pump for the boilers.

A workshop containing an engine, lathes, punching machines, blacksmith's shop, etc.

An electric dynamo (Gerard) for incandescent lighting.

A charging room for the tram-cars.

Stables for the rolling stock.

Offices for employés, ticket office, waiting-room, etc.

Coal yards and yards for road materials.

The operation of charging the tram reservoirs is made in a special room called the charging-room. The reservoirs should hold, before the start, 3,106 liters of air, and the heater 200 liters of water at a temperature of 155° C. The air and the steam which heats the water are brought to the charging-room by pipes—copper for the steam and iron for the air. These pipes end in orifices provided with screw cocks. The water in the heater is heated by passing the steam from the steam-pipe through it, and it is only refilled with water when the heater is emptied for repairs. For the operation of charging, the cars are brought opposite the cocks, and by means of connecting pipes the cocks are put in connection with corresponding cocks in the car. The duration of charging is about fifteen minutes.

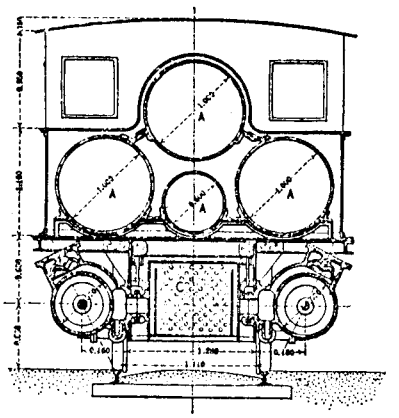
It has been found possible, however, in the case of prolonged runs, to have air pipes brought to the side of the track, and a partial refilling of the reservoirs effected while tickets are being taken, etc.; this takes only about three minutes.

There are two parts of the Nogentais tramway that might be called the main line and the branch; main line, 9,580 meters (31,432 ft.); branch line, 2,108 meters (9,916 ft.); total length, 11,688 meters (38,348 ft.)

On this line the track varies in its position; 6,550 meters (21,293 ft.) placed on the sidewalk and 5,138 meters (17,060 ft.) placed in the road or carriage way. The gauge, which is standard (4 ft. 8½ ins.), is increased by one-fourth of an inch on curves. The track set in the sidewalk is made of Vignolles or T-rails of 8 meters length and weighing 20.1875 kilos. the running meter (40 lbs. per yard), placed on oak ties of 2.2 × 0.14 × 0.1 meters (6 ft. 3 ins. × 5½ ins. × 4 ins.) dimensions, set apart 0.875 meter (34 ins.), center to center. These ties are cut in such a way as to give a cant to the rail of 1 in 20. The rails are fastened to the ties by iron screw spikes, and are joined to each other by ordinary fish-plates and four bolts with Trover nut-locks. The fishing of the rails is made over bridge joints, the ties being at this point 0.5 meter 20 ins.) apart, center

to center. The joints are not opposite each other, one being 0.5 meter (20 ins.) in advance of the other. The ballast here is 0.35 to 0.4 meter (14 to 16 ins. thick; 0.15 to 0·2 meter (5 to 7 ins.) of this is underneath the ties.

The part of the track placed in the road is of a different pattern. It is made of rails and flange-guards of steel 8 meters (26 ft. 3 ins.) long, which are exactly similar in section, and in each of which one side of the flange is narrower than the other. These weigh 17.925 kilos. the running meter (36½ lbs. per yard), and are joined by fish-plates. The rails and flange-guards are separated by a groove of 0.029 meter (1⅛ ins.) on tangents and 0.035 meter (1⅜ ins.) on curves. They are supported and held together on cast-iron chairs by bolts. These chairs are 0.25 meter (10 ins.) high, and their heads form jaws in which the foot of the rail is held at the proper angle of 1:20. The chairs in their turn are fastened by iron screw spikes on oak ties of the same dimensions as before, set, however, 1 meter (40 ins.), center to center. A number of cast-iron cross-bars, holding the foot of the rail, assure the firmness of the gauge. The fishing of the rail joints and the joints of the flange-guards is made between the ties, as in the other system, the ties being brought to within half a meter (20 ins.) for the purpose. The joint of the first rail is half a meter (20 ins.) in advance of that of the second, and the joint of the first flange-guard is opposite that of the second rail, and *vice versa*. These ties rest on a bed of ballast 0.05



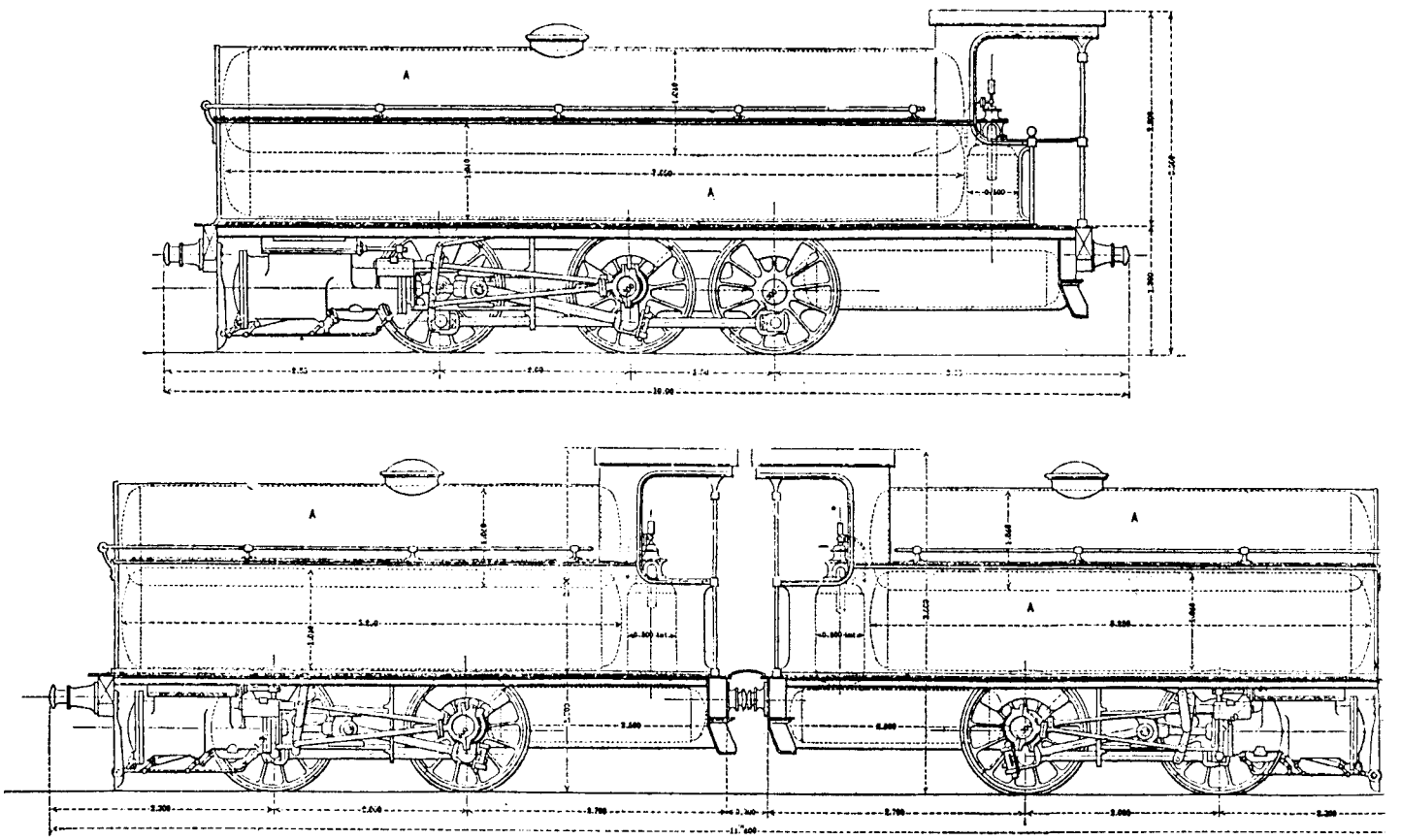


Fig. 5.—Forty and Fifty-ton Locomotives on the Compressed-Air System, designed

by M. Mekarski for the City of Paris.

to 0.15 meter (2 to 5 ins.) thick, and this ballast is leveled up to the top of the ties.

The track in the road is almost all paved; the height of the chairs allows a bed of sand 5 to 9 centimeters (2 to 3 ins.) deep to be placed between the lower surface of the paving stones, which are 0.2 meter (7 ins.) deep, and the top of the ties. Over a length of 560 meters (626 yds.) of this part of the track the rails are set in chairs 0.138 meter (5½ ins.) high and 0.14 × 0.2 meter (5½ × 8 ins.) base, weighing 9¼ kilos. (20½ lbs.) and resting on a bed of concrete of 0.15 meter (5 ins.) thick. This is paved with stones set in Portland cement. In this portion this special form was used on account of the shallow space allowed in crossing bridges, etc. Side tracks are established at various points to allow of passing of the trams going in opposite directions. The minimum distance apart in this case of the two tracks is 1½ meters (5 ft.), allowing a clear separation of the two cars of 0.6 meter (2 ft.)

The switches (Delettrez system) are automatic, allowing the car going towards the switch only to take the right-hand track, but by a spring the car, either on the side track or the main line, always keeps to the rails, moving the tongue of the frog. There are turn-tables at intervals, by which the car can be turned 90° or 180° by hand. Their diameter is 2.8 meters (9 ft.)

The following is an approximate estimate of the cost of the different types of track:

(*a*) Vignolles rails on the side track: Cost per meter, 20.53 francs ($4.11); cost per yd., $3.70.

(*b*) Vignolles rails, with special curbstone and sidewalks: Cost per meter, 29.87 francs ($5.98); cost per yard, $5.40.

(*c*) Track on the road paved between the rails and half a meter each side: Cost per meter, 62.54 francs ($12.51); cost per yard, $11.27.

(*d*) Track on the already paved road: Cost per meter: 33.23 francs ($6.65); cost per yard, $6.

(*e*) Track on macadamized road: Cost per meter, 35.68 francs ($7.15); cost per yard, $6.44.

(*f*) Track on a bed of concrete 15 meters thick, with paving set in Portland cement: Cost per meter, 69.02 francs ($13.81); cost per yard, $12.44.

Of course, in these figures account has only been taken of the cost of the track proper and of the prices of materials and of labor. Some other expenses regarding the locality have not been taken account of, such as a payment of $6,400 for bridge restoration, costs of grading and straightening roads, moving gas and water pipes, moving trees in the Bois de Vincennes, etc. These extra expenses added more than a fifth to the regular cost of the road.

In a supplemental report Mr. RATHBONE speaks of the application of this system to locomotives, as illustrated in Fig. 5. This engine was designed for use on a metropolitan railway, either in a tunnel or elevated, where steam would be objectionable. He says:

M. Mékarski shows that with a charged pressure of 50 atmospheres air locomotives might be constructed of an external form similar somewhat to steam locomotives, without tenders or smoke stacks. The air reservoirs occupy on the frame the place of the boiler, without obstructing the engineer's view. He has designed, with this idea, the two types of locomotive given in the plate, showing the side elevations of each and a transverse section. The first type in working order weighs 40,000 kilos. (44 tons). It carries three large cylinders charged each with compressed air. The second model is composed of two smaller carriages coupled back to back like a locomotive to its tender. The two form a locomotive of 50,000 kilos (55 tons).

The 55-ton locomotive is designed with a view to develop a tractive power of 6,000 kilograms (13,228 lbs.) and to run around curves of 150 meters (492 ft.). It is composed of two separate machines mounted on two coupled pairs of driving-wheels each. The reservoirs of compressed air are mounted on the two trucks, which are so arranged that a central cab, where the engineer is placed, is formed by the joined ends. The view from this cab is in no way obstructed by the reservoirs in either direction, and they are entirely hidden under a covering of sheet-iron.

The total length of the truck from end to end, including the buffers, is 14.4 meters (47 ft. 3 ins.); the greatest width is 3.2 meters (10 ft. 6 ins.), and greatest height above rails 1.3 meters) 4 ft. 3 ins. The diameters of the cylinders are, respectively, 0.26 meter (10¼ ins.) and 0.5 meter (19⅝ ins.); the common stroke is half a meter (20 ins.) Each of the four reservoirs is 5.2 meters (17 ft. 1 in.) long. Three of them have an internal diameter of one meter (39⅜ ins.); the fourth, smaller, is only 0.6 meter (23⅝ ins.) in diameter. The reservoirs are made of soft steel, 20 millimeters (¾in.) thick for the large, and 12 millimeters (½ in.) for the smaller one. The total capacity of one battery is 13 cubic meters (460 cu. ft); the weight of air compressed in them would be 800 kilograms (1,764 lbs.), or a total of 1,600 kilos. (3,528 lbs.) Each battery weighs about 10,500 kilos. 11½ tons).

There is a heater and a regulator on each part of the locomotive, but they are so arranged that by maneuvering one of them all the cylinders of both machines will be similarly affected. Besides the hot water in the two heaters proper, there is an extra supply of hot water in two reservoirs under each part of the cab—four reservoirs in all which communicate with the heaters. The total capacity of hot water in each machine would, therefore, be 1,000 kilos. (2,205 lbs.)

The air in this machine, after being used, passes through an arrangement which might be called a condenser. This is used in order that no moisture, even in minute quantities, might be deposited in the tunnels. It acts simply to connect the moisture in the exhaust air, and is in form similar to a tubular condenser for a steam engine.

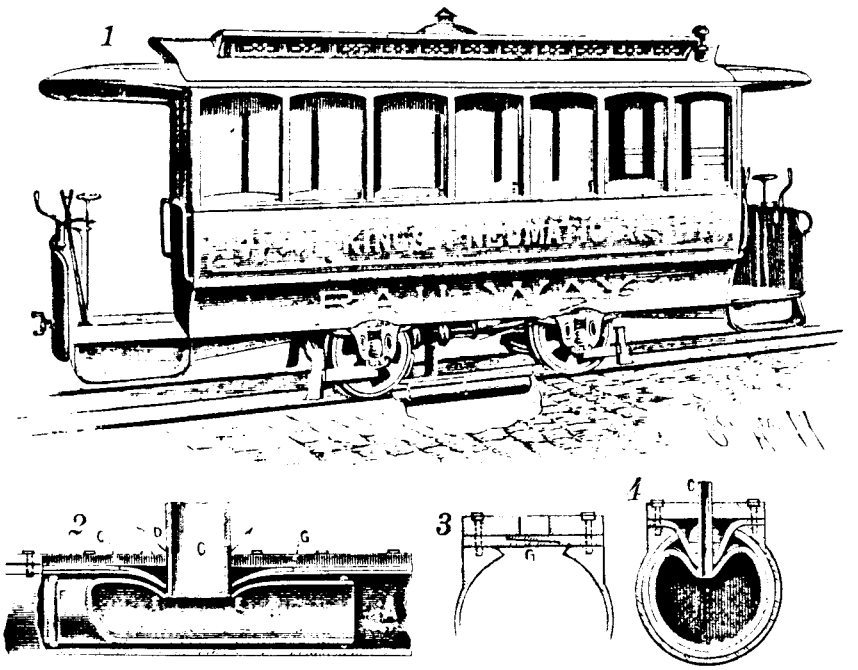
There is little to be said of the 44-ton machine, after having the preceding description, since it has very much the same characteristics. It is formed of a single frame, mounted on three pairs of driving-wheels, all coupled. The reservoirs are of the same diameter as in the 55-ton type, and are similarly placed, only varying in their length. It might be added that, no fireman being needed for these locomotives, a great saving in wages is effected, but this is nearly made up for in the extra labor, capital, and wear incurred in having the extra stationary plant.

Mr. H. A. SHACKELFORD, Consul at Nantes, adds as follows concerning the operations of the line in that city: The maximum grades in the line in Nantes are about 25 ft. per mile, but present no difficulties in operation. The cars used are clumsy and weigh twice as much as American cars. The cost of running a car, for a daily run of 60 miles, is as follows:—for coal and oil, $1.20; wages for operator and conductor (New York prices) $3 to $3.50; repairs to cars, $1.80; total $6.50 per day, or 10 to 11 cts. per mile.

AN IMPROVED PNEUMATIC RAILWAY SYSTEM.

The accompanying illustration represents a pneumatic railway system, patented by Mr. George W. King, designed to provide, by simple and efficient devices, a continuous air current to the motor on the car body, without leakage, and without friction or pressure on the valves, while requiring no radical changes in the permanent way. Fig. 2 is a longitudinal section of a portion of the air tube or conduit, Figs. 3 and 4 being cross sections, while Fig. 1 represents the application of the system on a street railway. The underground conduit is indicated at A in Fig. 2, and it has a continuous slot over which fold flap valves riveted to the edges of the slot, as shown at G in Fig. 3. The piston, B, consists of a tube of slightly less diameter than the air tube, and on its outer edges are packing rings, F, making a close joint between the tubes A and B, while the upper face of the piston has a central depression serving as a recess for the ends of the valves when they are depressed. A hollow connecting shank, C, is rigidly secured to the piston in this depression, the upper end of the shank being connected with any suitably constructed motor on the car body. The shank is elliptical in horizontal section, its ends serving as openers or spreaders as they pass along in the slot of the tube, making continual communication between the tube and the motor. To gradually open the flaps as the air-connecting shank passes along, the lower longitudinal faces of the latter are provided with horizontal cams having curved under faces, whereby, as the shank passes along the air tube, communication will be had between the atmospheric air and the air in the pocket or chamber formed between the piston B and the tube A, and so much of the valves as is necessary to be spread apart will be relieved of air pressure, thus reducing the frictional wear on the valves to a minimum. To effect such communication with the outer air, the shank, C, is provided with short vertical air channels, D, the upper ends of which open out above the conduit, while their lower ends open into the space, E, below the flap valves when in their lowermost opened position, whereby any compressed air in the pocket between the cylinders will escape. It is claimed that the cost of construction and maintenance under this system will be low, the cars carrying no unnecessary weight, and there being small loss of power by friction, while it is unaccompanied by noise, and the cars can be started and stopped without jerking. The necessary bells, gongs, brakes, etc., may all be worked automatically by the compressed air, which may also, after use in the motor, be utilized to assist ventilation when this is deemed desirable.

For further information relative to this invention address the patentee, No. 1251 High Street, West, Washington, D. C.



KING'S PNEUMATIC RAILWAY SYSTEM.

EN 7-5-90

The Mekarski Compressed Air System.

LONDON, June 16, 1890.

TO THE EDITOR OF ENGINEERING NEWS:

SIR: Seeing that you are giving a full account of the so-called "MEKARSKI" system of using compressed air for propelling purposes, and that you express a favorable opinion of giving a dose of heat to the compressed air before entering the cylinder, I beg to call your attention to the fact that this is not the invention of MEKARSKI at all, but was patented by an Englishman, one JAMES GLAZEBROOK, who in his Patent No. 2,164 of 1797 described the results obtained by passing the air through a vessel of heated water, and expanding it thereby.

In 1801, in his Patent 2,504 of that year, he further describes his improvements on his first patent, and proposes using it to propel pistons or other mechanical apparatus, as you will see by referring to his two specifications.

Feeling sure that you desire to record nothing but facts in your valuable and interesting journal, I send you this information.

Some years ago a gang of company promoters in London got up a company to purchase this "invention," but finding from these patents that the whole matter was public property and that consequently they had nothing to sell, and that the public had nothing to buy, it "burst up," to the great disappointment of the promoters, who had stood in for a good "pull" out of the pockets of the public. CHAS. F. T. YOUNG, C. E.

[Certainly it was not with any intention that it was even implied in anything we published that giving a "dose of heat" to compressed air was in any sense original with MEKARSKI, or any other inventor of the present generation. It has been used in a dozen different plans for working compressed air within the past 20 years, and long since we should have said had become an axiom of engineering. GLAZEBROOK may well be the first who ever discovered the useful effect of such heating; we know of no evidence to the contrary, at any rate. The great benefit of the process is that it converts the heat so applied into power at nearly its theoretical efficiency, and that it will do so is so evident from our modern knowledge of thermodynamics that no special credit could attach to any contemporaneous suggestions of the kind, even were it novel.—ED. ENG. NEWS.]

SRJ 12-91

Compressed Air Motors at Toledo.

The Toledo Consolidated Street Railway Co. of Toledo, O., has been making a number of experiments recently with compressed air as a motive power, with very satisfactory results. The system used is the Mekarski, and is similar to that which has been in operation for a number of years in Nantes and other parts of France, and which was described in our last issue. The motor car now in use on the Consolidated company's line was built for the American Mekarski Compressed Air Motor Co., by the Rand Drill Co. of New York, and carries eight tanks for the air, which are charged with an initial pressure of 600 lbs. With this charge the car is capable of running eight and a half miles without recharging, and of drawing another car at a speed of twenty miles per hour. We are informed that the Consolidated company are so well pleased with the equipment that they have ordered twenty-six additional cars equipped with the same system.

In view of the results obtained with compressed air abroad, the results of its operation in this country will be watched with interest.

THE following is the exact copy of a response made by a witness to an accident on one of the Los Angeles cable cars: "I think the lady was to blame some as well as the conductor she was a litel slow in geting off and got off back formost which is olmost sure to throw one. I also think the conductor puled the bell rope a litel to quick do not think he done it apurpes do not think she was much hurt only seteled hur dinner."

Street Railways of Toledo, O.

Toledo is peculiarly fortunate in possessing enterprising street railway companies. To them the city owes not a little of its prosperity. They have provided the most approved rapid transit facilities, and they are constantly increasing the efficiency of their service. They have been greatly instrumental in making Toledo a desirable place of residence. The two companies cover the city thoroughly, so that it is possible to reach almost any point within the municipal limits quickly and conveniently. They provide rapid transit; one of them at the present time operates all its cars by electricity; the other company employs the same power for running the great majority of the cars. Within a year horses will be abandoned on all the lines.

TOLEDO ELECTRIC STREET RAILWAY COMPANY.

The Toledo Electric Street Railway Co. occupy sixteen and a half miles of street, on which are laid twenty-four and a half miles of track.

The power house of the company is located on Water Street between Oak and Adams Streets. The building has a frontage of 100 ft. and it is 165 ft. in depth. It is one story in height, but it is an exceedingly high building for a one story structure. When one visits the plant he is struck first of all by the wisdom of the owners in providing an abundance of room for increase in capacity.

Twice the amount of power now generated may be required on the road, and the necessary machinery can be located in the building, with an abundance of room to spare. So many electrical plants have outgrown their quarters, especially those intended for lighting, that this characteristic of the Toledo company's station may be referred to as an especially commendable feature.

The boiler room is located in the front of the building. The boilers now installed are four in number; they are tubular, and were manufactured by Stewart & Sons of Worcester, Mass. Two, and at times three, boilers generate the steam for the engines.

Coal is now used as fuel. Natural gas was used until November 1, when the general supply was not sufficient to meet the requirements of consumers in the city. Manufacturers and owners of steam plants were forced to use other fuel. About the first of April, when the demand from residences is much less, the company will resume the use of gas.

The power house was constructed with a view to securing solidity and freedom from vibration. The walls rest on 800 piles; 700 piles were driven in the space inclosed by the walls. All the machinery in the engine and generator room, that is, the engines, counter shafting and dynamos, rests on exceptionally massive masonry. The floor is covered with concrete to the depth of from one to four feet. The entire interior is perfectly free from moisture. The two engines were manufactured by C. & G. Cooper & Co., of Mount Vernon, O. They are of 450 and 500 H. P., but upon occasions they have developed 600 and 700 H. P. respectively. They are cross compound condensing. Water for condensing is secured from the Maumee River directly in front of the power house. The flywheel of the large engine weighs 55,000 lbs. and that of the smaller 42,000 lbs. Belts made by the Jewell Belting Co. are used throughout.

Eight generators supply the current. Six of these are Thomson-Houston machines of eighty H. P. each. The other two are Westinghouse four-pole machines of 200 H. P. each.

In operation the plant proves extremely economical. From six to eight men, including firemen, engineers and generator men, operate the plant for the entire twenty-four hours.

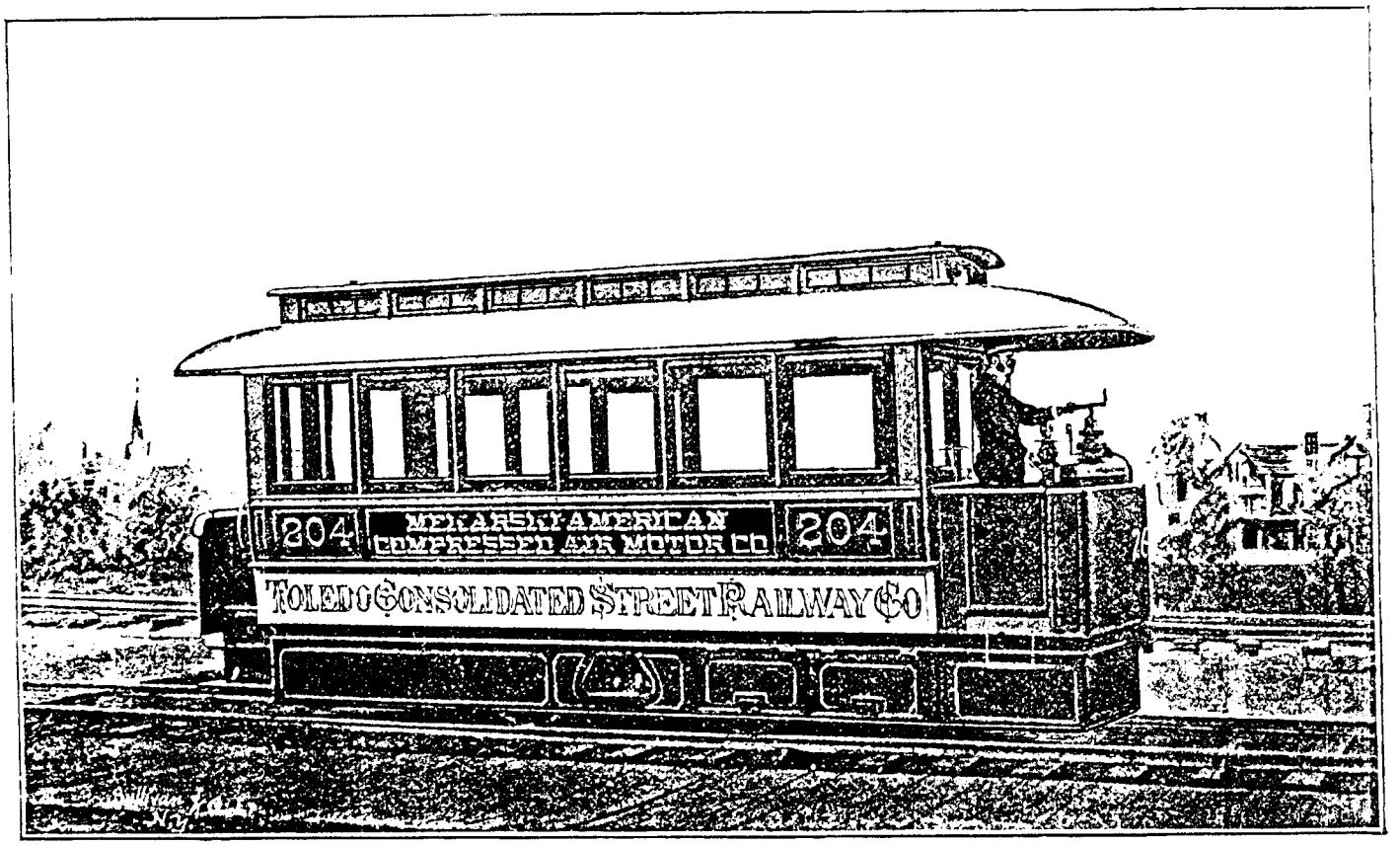


FIG. I.—MEKARSKI COMPRESSED AIR MOTOR CAR—TOLEDO CONSOLIDATED STREET RAILWAY CO.

Until the recent fire, described in our last issue, which destroyed one of the car houses containing a considerable part of the equipment, the company operated forty-four Westinghouse single reduction motors of twenty H. P. each, six Thomson-Houston S. R. G. motors and ten double reduction Thomson-Houston motors of thirty H. P. each. Two special motors built by the company were also operated. The machines are somewhat different from the ordinary type. The fields are run in series, and, it is stated, excellent results both in speed and power have been obtained. Brill cars and trucks are used exclusively on the road.

The company has had two car houses. One of these has just been finished at the corner of Ontario and Galena

Streets. It has a frontage of 125 ft. and is 175 ft. in depth. It has ten tracks, and is provided with pits for the examination of motors. It is a well lighted and well arranged structure. The company's other car house on Canton Avenue corner of North Street, was recently burned.

Heating on some of the cars is effected by an electric heater constructed on the company's own design. It is extremely simple. Imagine a four-foot section of water spout constructed of zinc, and little need be added to the description. This cylinder is heated by passing a current of electricity through it. The bare metal is covered with asbestos cloth and then with canvas, and treated with a coat of shellac. Four of the heaters are placed in the car; they are hung just far enough below the seat so that passengers may rest their feet against them.

The officers of the company are David Robison, Jr., president; L. S. Baumgardner, vice-president and James J. Robison secretary and general manager.

TOLEDO CONSOLIDATED STREET RAILWAY CO.

The Consolidated Street Railway Co. of Toledo has an extensive system. Its twelve lines aggregate sixty-five miles, of which forty are operated by electricity at the present time; the remainder is traversed by horse cars. The company proposes to utilize electric motors on all its lines, and within the next year all the horses will be out of employment. It gives an admirable service. All the lines are now laid with heavy girder rails with the exception of fifteen miles on which a substantial steel tramway construction was built within the last four years. Seven-eighths of the lines are paved; indeed, thirteen miles of paving was done last year. During next year the company will build four miles of track in new territory, and will put in double tracks on several old lines.

The main station of the company is located at the corner of Water and Monroe Streets, fronting on the latter street. Its dimensions are 110×240 ft. The front part of the structure on the ground floor is used as a car shop. It is conveniently arranged with pits so that motors can be readily inspected. The repair shops are also located here. Directly overhead is the winding room, and excellent work in winding armatures and coils is done.

The power station is in the rear of the building. This portion of the building is entirely fireproof. The boiler room contains four Wharton-Harrison boilers, each of a capacity of 150 H. P. Crude oil is used as fuel. The Reed oil burner, furnished by the Standard Oil Co., is employed. Until within a short time natural gas was used; when the supply was cut off the resort to oil was made, and the change has proved so entirely successful that it is questionable if a return will be made to gas. The boilers are arranged for either kind of fuel. The oil is stored in a reservoir located on a dock in the rear of the building. It is brought to that point from the railroad yard in a small tank car which the company runs over its lines. The live steam purifier which is used is set below the water line of the boilers. It is of the type manufactured by Stilwell & Bierce, of Dayton, O. A Dean pump is used for forcing the water into the purifier and thence into the boilers.

On the same floor are located the engines, which are the Hamilton-Corliss, compound condensing, of 500 H. P. each. Water for condensing is taken from the river. In the same room is located the air compressor used in connection with the Mekarski compressed air motor shown in Fig. 2.

The generator room is directly above, the engines belting to a line shaft. The main belt, which is forty-eight inches in width, was made by Charles Munson & Co., of Chicago. Current is generated by two Edison machines of 250 H. P. capacity and five Thomson-Houston 80,000 watt machines.

The company are operating at the present time thirty-nine double reduction Thomson-Houston motors of fifteen H. P. each, and five Eickemeyer motor cars; four of these

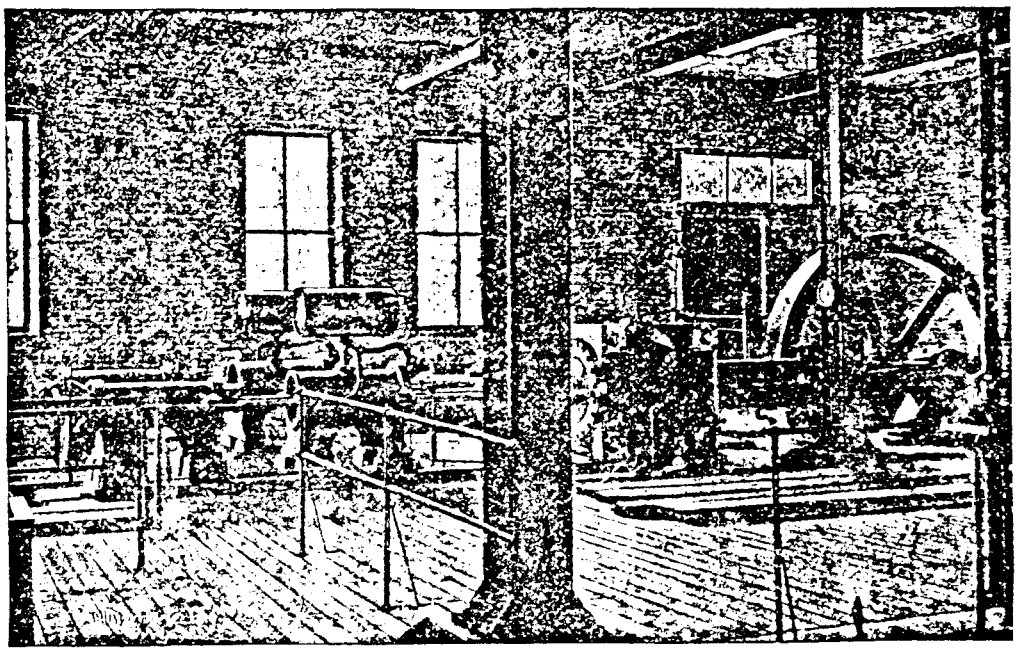


FIG. 2.—AIR COMPRESSOR—TOLEDO CONSOLIDATED STREET RAILWAY CO.

latter are double connected and the other is single connected. The capacity is thirty H. P. each. These motors, which were built by the Western Electric Co., of Chicago, are giving entire satisfaction. Six additional motors of this type will soon be put in operation. The electrical equipment of the road is working excellently and to the satisfaction of the residents of Toledo. There are several points in the road where, owing to the branching of several lines at one point, there has been some complicated construction, but all problems have been satisfactorily solved. The officers of the road are: Norman B. Ream, Chicago, president; Albion E. Lang, vice-president and general manager; William E. Hale, Chicago, treasurer; Charles L. Wight, secretary.

The Mekarski American compressed air motor car shown in Fig. 1, is in use on the road; it has been in operation a little over three months. It is giving satis-

faction and as this is the first car of the kind built in this country, those interested are greatly encouraged by reason of the record that the car has made. It is twenty-two feet over all. The eight cylinders which contain the compressed air are located below the floor. They are made of steel plate three-eighths of an inch in thickness. The air pressure is 600 lbs. to the square inch. The compressed air engines are two in number, each of fifteen H. P. with cylinders 5 × 8 ins. The engines, with all their gearing, are encased in wrought iron with two doors opening on the side. The under frame of the car is of wrought iron or steel. On the front platform is placed a reservoir containing hot water, through which the air passes on its way to the motor cylinders. The reservoir is fitted with a valve, which regulates the air so that it can be used at any pressure desired. At the right hand of the driver is the ordinary lever for working the link motion. The brake is formed by two vertical cylinders placed on either side of the car between the wheels, a small pipe coming from the three-way cock carries the compressed air under the piston for working the brake. The car will run between eight and nine miles without recharging, and is handled with ease and promptness, all the motion being under perfect control, and requiring but a slight expenditure of physical force on the part of the driver. Its speed varies, at the will of the driver, from three to twenty-five miles per hour. It can be brought to a dead stop, it is claimed, in less than its own length.

THE

ENGINEERING MAGAZINE

VOL. III. AUGUST, 1892. NO. 5.

COMPRESSED AIR FOR STREET-CARS.

By General Herman Haupt, C. E.

IN view of the objections to the overhead electric system for propulsion of cars on surface roads in cities, the annoyance from tearing up streets and the cost of plant and maintenance of the cable lines, the expense of horse power, with the sanitary evils resulting from the location of stables in populous cities, the fact that pneumatic motors, after a successful demonstration of their superiority, have been largely overlooked seems inexplicable. These motors not only are entirely free from the objectionable features of the other systems, but they furnish a mode of propulsion which is more safe and more economical than any other with equal velocity of transit. These assertions are made advisedly and are based on actual demonstration.

In 1878 and 1879 five pneumatic motors were constructed upon the plans and under the supervision of James Hardie, Mechanical Engineer, and were run for several months on the Second-avenue railroad in New York with perfect success. In 1879 the writer was called upon in the interest of proposed investors to investigate and report upon the practicability and expediency of using pneumatic power for street railroads. The comparative results were overwhelmingly in favor of motors of this class, but all attempts to secure their general introduction at that time proved failures.

The position taken by the officers of horse-railroad companies, both in New York and Philadelphia, was that any car running along city streets without horses in front would frighten horses, cause runaway accidents and subject companies to suits for damages. This objection of course applies with much greater force to the cable and trolley systems, which are accompanied by a loud humming noise, while the pneumatic motor can have a noiseless exhaust; but no argument or explanation availed in the face of this senseless objection. One railroad president declared that if the motor were adopted by his company it would be necessary to kill some of his old horses, stuff the skins and mount a pair of them on a low truck in front of each car!

The attempt to introduce pneumatic motors was thus found to be premature in 1879. The company could make no progress and finally abandoned all effort, losing the capital expended in plant and demonstration, and no attempt to revive the motor has since been made. But the engineer and inventor, Robert Hardie, now in the service of the mechanical department of the Columbian Exposition at Chicago, retains unshaken confidence in the superiority of the pneumatic motor.

Conditions existing now seem favorable for the introduction of a motor which, free from the objections to all other systems, with no new defects of its own, may be considered as perfect. No fears are now entertained that a car running without horses in front will make a stampede of all equines on the streets traversed, and this in 1879 was the only reason urged in opposition to the introduction of the pneumatic motor. It is possible, therefore, that a few extracts from the report made in 1879 may be of interest at this time.

The compression-plant was located in Harlem in New York, on the line of the Second-avenue railroad. It developed 66 horse-power and charged the cylinders under a car with compressed air

in seven minutes. With proportionately larger plant not more than one minute would be required. The report of Mr. Hardie stated the capacity of the cylinders under the seats at 17,000,000 foot-pounds of work, capable of running a car sixteen miles on a level. The effect of the compressed air was greatly increased by passing it through a tank of hot water at the temperature due to 80 pounds pressure. The tank had a capacity of five cubic feet and was placed on the side of the platform.

The writer has not at hand a copy of his full detailed report, but only an abstract of some of the results, which will be given here.

A duty of nearly 50 per cent. of the horse-power used in compressing air can be secured from the expansion and utilization of dry air when compressed; and, by using stationary, compound or condensing engines, four times the power can be obtained with a given cost of fuel, as compared with ordinary steam-motors, which more than counterbalances the loss in compression. By the addition of a heater and passing the air through hot water an increase of nearly 100 per cent. power can be secured at a merely nominal cost.

On a straight and level road, with 160 cubic feet of air in the reservoirs, under an initial pressure of 350 pounds, the motor would run seven miles with a reserve of one-third left in the reservoirs on its return. This result assumes that the amount of air expended at each stroke is equal to a full cylinder of air expanded to atmospheric tension, but actual work has demonstrated an ability to run ten miles with a single charge, proving that less than this quantity is sufficient. The back pressure which would result from working against a vacuum is relieved by suction valves in the exhaust passages.

In descending grades the motor cylinders act not only as brakes, but also as air-pumps, and have power to pump back into the reservoirs, against a pressure of 200 pounds, sufficient air to raise the gage-pressure seven pounds in running 2100 feet, and restore sufficient air, when heated, to run the motor half that distance upon a level. By this remarkable contrivance power can be stored on descending grades. The down-hill portions not only use no power, but give back a portion of that which was expended in ascending.

The compressed air can be used expansively to any extent, and cut off at any part of the stroke. It can act as a brake, or the motor can be instantly reversed, and the braking apparatus is exceptionally complete and satisfactory.

The power of an eight-ton motor is sufficient to propel three cars on a straight and level road. With full power in the motor cylinders and full adhesion on the rails the motor can overcome grades of 300 feet to the mile.

Although, during a run, the pressure in the reservoirs is constantly diminishing, yet, by means of a reducing valve, the working pressure in the motor cylinders is maintained at a constant limit.

Each motor, allowing for increased speed, would take the place of ten or fifteen horses, the cost of which would about equal the cost of the motor, $1500.

The system would be particularly adapted to suburban localities and would afford better facilities for rapid transit than are now afforded by elevated roads, for while the speed would be equal to twenty miles or more per hour, the stops need not be limited to stations, but could be made at any point.

With the small class of motors, three cars, or two in addition to the motor, can ascend grades as steep as any usually found on horse railroads. This is a point of the greatest value for public accommodation. It will enable a company to utilize all its old cars and supply additional cars at the hours when the rush of travel requires them without additional expense for power or conductors.

The Delamater Iron Works offered to supply a compression plant of sufficient capacity to charge one car per minute for $20,000.

Compressed air can be transmitted to any distance without loss except for friction in pipes. If pipes are large and velocity low the loss will be inconsiderable. Several lines could therefore be operated from a large central plant and in many localities natural water-powers could be utilized to compress air and the compressed air transmitted by pipes to charge motors, generate electric currents, or drive machinery by direct application to cylinders.

To charge motors at a central station a nozzle between the tracks and a short piece of pressure-hose to screw on to the air reservoir is all that would be required to connect with reservoirs located in a building. It would not be necessary to run the cars into a house to renew the air-supplies.

The running expenses are less than one-half—in fact, the estimate shows less than one-third—the cost of horse power. The motors run without noise, ashes or smoke, are perfectly under control and would furnish the best possible power to operate elevated railroads. Skilled engineers are not required. An ordinary car-driver can be taught to run an engine in a single trip.

No flues can be burned or boilers exploded though carelessness, and as air-reservoirs last indefinitely, explosions in transit from

causes which render steam dangerous are impossible. Even if an explosion should occur by a rupture it would be while charging the reservoir at the time of maximum pressure and not in transit, and the air would simply escape with a hissing sound ; cold, not heat, would result from the expansion.

The car acts as its own governor and no more air can be used than is necessary to overcome the resistance ; there can be no waste. There are no horses in front to obstruct a clear view of the track. At a speed of twelve miles per hour the motor can be stopped on a level within its length, and the braking apparatus cannot get out of order so long as the motor can move at all.

The pneumatic motor would be peculiarly adapted to underground roads, as the escape of pure air would assist in the ventilation, but it is the best possible for all urban or suburban roads, whether elevated, surface or in tunnels.

In this paper results only have been given, but the full report made in 1879 gives the facts upon which the conclusions have been based.

A detailed estimate was made from data furnished by the operations of the Second-avenue railroad and a comparison of cost of operation by horse power and by the pneumatic motor. In this estimate it was assumed that a compression plant was located at each end of the route, requiring double the expenditure for plant and double the expense of operation over a single plant located in the middle of the run, which would answer just as well. The estimate for pneumatic power was designedly made in excess, so that errors would be on the safe side, and the cost of horse power was from actual results on the Second-avenue railroad.

On the basis of 16,000,000 passengers carried on this road in 1878, the year previous to the report, the actual results of operation by horse power were :

Running expenses per passenger in cents	2.88
Estimate by pneumatic motor	0.93
Cost per passenger by horse power, including general expenses and a six per cent. dividend	4.55
Estimate by use of pneumatic motor	2.57

The dividend was $72,000=0.45 cents per passenger.

The conclusion from the data furnished was that a very small increase in the number of passengers would permit the company to sell ten tickets for 25 cents and still pay fair dividends upon the capital invested, besides furnishing a rapid transit the speed of which would be limited only by considerations of safety.

But all these demonstrations and representations, backed by the very strongest indorsements of the daily press in New York and by the actual running of five motors daily for a period of several months, availed nothing against the senseless cry, "It will scare horses," or, "The motor cannot be run unless we put stuffed horses in front of each car." It is true that horses on the opposite track did at first prick up their ears, look at the motor and shy a little, but they never gave any trouble and soon became accustomed to it, and no case of a runaway accident with street vehicles was heard of, but prejudice, which proved all powerful to exclude the pneumatic motor at that time, did not prevent the introduction of the trolley and cable systems very soon afterwards.

THE MEKARSKI COMPRESSED AIR TRAMWAY AT BERNE, SWITZERLAND.

The application of compressed air for the propulsion of street cars has been a fruitful source for the design of various inventions and devices, only a few of which have proved practically successful. Among the successful systems is the well known Mekarski system, described and illustrated in our issues of May 24 and 31, 1890. For suburban lines and lines with light traffic the advantages of independent motors are very considerable. The Mekarski system is in regular operation at Nantes and Paris, France, on lines which are practically level, but it has also been introduced in Berne, Switzerland, on a line about two miles long, with grades of 0.25% to 3.7% and 5.2%, and has been in regular operation for over twelve months.

In the Mekarski system the air is compressed by a stationary plant and forced into storage cylinders carried under the car, the air passing to a pair of driving cylinders, and operating the engine by expansion in the cylinders, in the same way that steam is used in a steam engine. A special feature of the Mekarski system is the heating of the air, to maintain it at a constant temperature, by passing it through superheated water at 330° F. The air thus becomes saturated with steam, which subsequently partly condenses, its latent heat being absorbed by the expanding air. Without this, the temperature of the air would fall so rapidly that it would be practically useless for motive power.

In the compressor station are four compressors, driven by gearing from a shaft driven by belts from the turbines at the city's power station. The compressors are horizontal, of 35 HP. each, and three of them are in regular operation, with the fourth for reserve. The turbines and main shaft make 130 and 207 revolutions per minute, respectively, and the compressors make 80 strokes per minute. Each compressor has two cylinders, the larger one compressing the air to 73 lbs. per sq. in. and the smaller one to the maximum of 469 lbs. per sq. in. The pressure in the car reservoirs is 440 lbs. per sq. in. From the main tanks the air is conveyed in pipes, crossing the river Aare by an iron bridge erected for the purpose, to the charging station, where it is stored in iron reservoirs or accummulators of 31.4 ins. diameter, and 44.15 cu. ft. capacity. These are placed at the back of the car shed, where there are also three vertical boilers to supply the steam and water for the heating chamber on each car.

The following is an abstract of an article in "Engineering," of London, by Mr. C. S. Du Riche Preller, describing the line at Berne:

The car shed, to which are attached a repair shop and the company's offices, contains four parallel lines of rails provided with a cleaning pit each, and intercommunicating by a transfer table, and a turntable, there being no outside space for sidings. Three tracks are loading lines, two being used during the day exclusively for the cars running in for loading and out for service, while the third is used for one or two cars standing always ready loaded in case of accident or special service, and the fourth track serves for the empty reserve cars and those undergoing repair.

The charging plant is placed at the end of the three loading tracks, and consists of four superposed horizontal pipes of 1.2 ins. inside diameter running along the wall, and of the gage, regulator, and valve apparatus surmounting them, and fitted in the center. The uppermost of the pipes connects direct with the main from the air-compressing station, which passes through the accumulator room, and there also connects

with the accumulator battery. The second pipe connects with the accumulators, but is also connected with the compressed air main; the third is the steam pipe, and the fourth the water pipe, both connecting with the boilers in the accumulator room. The discharge from these pipes, on the loading of the cars, takes place through upright connecting pipes and two valves governed by two corresponding sets of regulators marked "Water" and "Air" respectively, the pressure in the compressed air, accumulator, and steam pipes being registered by three corresponding pressure gages fitted above the valves and regulators. There being only one valve regulator and gage apparatus for the three lines of rails, one car only, stationed on one or other line, can be loaded at one time, the connections of the other two lines being cut off in the meantime. This is a disadvantage, especially when an increased ordinary or an extraordinary traffic on special occasions requires the dispatching of several loaded cars in quick succession; and to meet this contingency each line of rails should be provided with its own regulator, valve, and gage apparatus, so as to enable two or three cars to be loaded simultaneously.

Each car, with front and back platforms, rests on two iron frames. The lower edge of the outside frame, composed of plates and angle irons, with diagonal bracing, is 5.9 ins. above the head of the rails, so that the compressed air cylinders, as well as the motors, are effectually concealed and protected. The smaller inside center frame serves for the axle bearings, the motor cylinders being placed between the two frames.

The engine is constructed like an ordinary steam tramway locomotive, and drives two coupled axles, the wheel base being 5.2 ft. It has a pair of outside horizontal cylinders, 5.1 × 8.6 ins.; four coupled wheels, 27.5 ins. diameter, and the total weight of the car when full is about 9.5 tons. The authorized speed is about 7 miles per hour. Taking the resistance due to the grooved rails and to curves under unfavorable conditions at 30 lbs. per ton of car weight the engine has to overcome on the steepest grade, 5%, a total resistance of about 0.63 ton, and has to develop 25 HP. At the maximum authorized working pressure in cylinders of 176 lbs. per sq. in. the motors can develop a tractive force of 0.64 ton. This maximum is, therefore, just sufficient to take the car up the 5.2% grade, while on the flatter sections of the line the working pressure does not exceed 73 to 147 lbs. per sq. in. Sand has to be frequently used to increase the adhesion on the 2% to 5% grades.

Between the two car frames are suspended ten horizontal compressed air storage cylinders, varying in length according to the available space, but of uniform inside diameter of 17.7 ins., composed of riveted 0.27-in. sheet iron, and tested up to 588 lbs. per sq. in. These cylinders have a collective capacity of 64.25 cu. ft., which, according to Mr. Mekarski's estimate, should have been sufficient for a double trip, 3¾ miles. The trial trips, however, showed this estimate to be inadequate, and two further small storage cylinders had therefore to be added of 5.3 cu. ft. capacity each. These had to be placed lengthways under the seats of the car, bringing the total cubic contents of the 12 storage cylinders per car up to 75 cu. ft., divided into two groups, the working and the reserve battery, the former of 49 cu. ft., the latter of 26 cu. ft. capacity.

A pressure gage indicates to the driver at all times the pressure to which the air inside the valve-box has expanded, while by means of a three-way valve the air, under reduced pressure, is allowed to pass either to the cylinders of the motors or to those of the brakes, or is entirely cut off. On the right of the driver there are fixed to the heating chamber three other valves, of which two are used for loading air and steam, and a third admits the air coming from the loading station into the working and reserve storage cylinders or batteries of the car, the pressure in these batteries being registered by two separate pressure gages.

Each car is provided with an air brake, consisting of a pair of small cylinders into which compressed air is admitted by the three-way valve already mentioned, and whose pistons act upon the brake blocks. Besides this air brake each car carries a single-acting hand-screw brake.

There are 16 seats inside the car and 12 standing places on the back platform, making 28 passengers, or, together with the driver on the front platform and the conductor, at 165 lbs. each, a load of 2.25 tons. The weight of the car, including compressed air, is 7.25 tons, the total weight therefore 9.5 tons, while the width is 6.56 ft., and the total length 23 ft., with a wheel base of only 5.25 ft. The overhang of the back platform, 8.65 ft., is excessive, the more so as the load of 12 passengers and the guard which it has to support equals nearly 1 ton, or 45% of the entire passenger load, and is insufficiently balanced by the heating chamber and passenger load in the front part of the car. On the other hand, the closed part of the car, with only 16 seats, is too small, and the car as a whole can certainly not be said to be well proportioned. The noiseless motion of the car renders a loud and effective caution signal necessary, and this, instead of the usual bell or whistle, consists of a horn, the car showing, moreover, at night, large red and green lights on the right and left, and two large white lights with reflectors on the front or driver's platform, on which is also placed a small coke stove which supplies hot water for heating the car during the winter season. The cars are fitted with two buffers in front, and a coupling bar at the tail for attaching a trailing car, which, however, is never done on the Berne line.

With an experienced staff, the operation of completely refilling and loading an empty car in the morning and getting it ready for service takes about 30 minutes; that of reloading and turning a car during the day occupies about 15 minutes, the work of reloading, properly speaking, being performed in about eight minutes. Each car in its turn remains at the station one day out of seven for the cleaning of the machinery and the regulating of the brakes.

The main line traverses the town from east to west, and measures two miles, within which, being a single line, it has about eight passing places about 66 yds. in length. The curves have a minimum radius of 164 ft. on the main line, and 98 ft. in passing places and terminal sidings represent 27% of the whole length, while the steepest grade is 5.2%. The track consists of grooved "Demerbe" rails and automatic turnouts, without cross-ties or longitudinals under them. The rails rest on a gravel foundation, or on concrete where the soil is loose, and are kept to gage by flat iron tie bars 6.56 ft. apart. It is surprising that this type of tramway rail should have been adopted, seeing that it is everywhere being replaced by the Phoenix girder rail, or the Haarmann or the Marsilion system (double flange rails). The inherent defects of weakness and of insufficient depth of groove of the Demerbe rail go a long way to account for the considerable extra resistance which the cars at Berne have to overcome, more especially on curves where the grooved rail, moreover, precludes the gage being widened. As the line is being laid in the center of the paved roadway, the outer rail is not raised, except in a few places where the superelevation is 1 in. The width of excavation for laying the permanent way is 6.56 ft. to a depth of 10 ins. The weight of the rails and track, including fastenings, is 66 lbs. and 142 lbs. per yd., respectively. The extensions will be laid on one side of the road with heavy and deep-grooved Phoenix girder rails, although on suburban roads single flange rails, with guard rails on sharp curves and at cross roads, would be at once more efficient for adhesion, and more economical, seeing that the present cost of Phoenix track is, including laying, $4.75 per yd:, as against only $3.75 per yd. of line laid with 40-lb. to 44-lb. flange rails. Pending the erection of the requisite new compressed-air plant, the suburban extensions are to be worked with 17-ton steam locomotives.

The total cost of the main line, including turbine transmission, compressing, accumulator, and loading stations, carshed, repair shop, offices, passenger huts at stopping places, and 10 motor cars ($3,000 each, complete), was $92,000, equal to $48,960 per mile.

The works of the line were carried out under contract by Mr. Anselmier, of Berne; while the compressed-air plant and motor cars were supplied by the Berne Maschinen Fabrik, from the designs of Mr. Mekarski, of Paris. The inadequacy of the calculations and estimates in some important particulars, in relation more especially to the supply of compressed-air and to the tractive force of the motor cars, entailed during the execution of the works a good many modifications and consequent delays.

The number of single journeys made per day of 14 working hours is 160, equal to about 300 car-miles, the mean number of passengers in the year 1891 being 3,140 per day, or about 20 per car journey. The carry-

ing capacity of 28 passengers per car was therefore utilized at the mean rate of about 60%. The population of the city of Berne being 50,000, the traffic on the line was equal to 23 passengers per head of population, which is a fair criterion for the first working year on similar tramways. The authorized fares are at the rate of 2 cts. per mile; the gross earnings in 1891, which were greatly in excess of the original estimate, amounting to 40,634 fr. per kilometer, or $13,000 per mile, equal to $250 per mile per week. During the whole year the service was carried on with the greatest regularity, except during the severe frosts in the winter of 1890-91, when it was occasionally interrupted, owing to the supply of compressed air failing, consequent upon ice forming in the old main pipe. This ice had to be dissolved by the pipe being embedded in hot sand. The removal of snow from the line after an exceptional fall was speedily effected by a salt trolley provided for the purpose. The working expenditure works out as follows:

	Per mile, $.	Per car-mile, cts.	Per cent.
Administration	865	1.48	8.3
Maintenance of line	385	0.66	3.7
Traffic	1,770	3.00	16.7
Motive power	6,045	11.74	60.0
Sundries	565	0.96	5.8
Total	10,530	17.84	100.0

Motive Power.

	Per car-mile, cts.
Wages, $20	5.86
Turbine power, per HP., oil, fuel	3.72
Maintenance and renewal of plant and motors	1.80
Sundries	0.80
Total	11.74

As the gross receipts were 21.4 cts. per car-mile, the working expenses are equal to 83% of the former, and the net earnings of $2,155 per mile represent already in the first working a return of 4.4% on the capital cost of the undertaking.

From the results of six official trips, of which the details were published at the time by Mr. A. Bertschinger, C. E., of the Federal Railway Department, the writer has worked out the varying pressure and the mean consumption of air during a double journey per motor car, as follows:

Storage cylinders.	Working. lbs. per sq. in.	Reserve. lbs. per sq. in.
Pressure of air on starting	440	440
Pressure of air at end of up journey	176	200
Pressure of air at end of down journey	103	176
	Lbs.	
Consumption of air at end of up journey	92	
Consumption of air during down journey	31	
Consumption or air during both journeys	123	

This has been fully confirmed by the working experience of 1891, when the consumption of air per motor car and double journey was as follows:

Minimum, 103 lbs	28	lbs. per car-mile.
Maximum, 154 lbs	42	" " "
Mean, 123 lbs	35	" " "

The principal advantage of the compressed-air system for urban and suburban tramway traffic as worked at Berne consists in the pleasing appearance of the motor cars, if properly proportioned; in the absolutely smooth and noiseless motion; in the total absence of smoke, steam, or heat, of overhead or underground conductors, of the more or less grinding motion of most electric cars, and of the jerkey motion to which underground cable traction is subject. On all these grounds the system has fully vindicated its claims as being preferable to any other so far known system of mechanical traction for street tramways. Its disadvantages, on the other hand, consist in the extremely delicate adjustment of the different parts of the system, in the comparatively small supply of air carried by one motor car, which necessitates the car returning to the depot for refilling after a run of only four miles or 40 minutes, although on the Nogent and Paris lines the cars, which are, moreover, larger, and carry the outside passengers on the top, run seven miles, and the loading pressure is 547 lbs. per sq. in. as against only 440 lbs. at Berne. Longer distances in the same direction would involve either more powerful motors, a larger number of storage cylinders, and consequently heavier cars, or loading stations every four or seven miles; and in this respect the system is manifestly inferior to electric traction, which easily admits of a line of 10 to 15 miles in length being continuously fed from one central station without the loss of time and expense caused by reloading. The working expenditure at Berne was, in 1891, 1.4 cts. per passenger; the gross receipts being 2 cts. per passenger, so that lower fares than those charged, viz., 2 cts. per mile, would not be remunerative. Moreover, the percentage of working expenditure can be kept within 83% only by the low cost of the primary hydraulic motive power. If, instead of by water power, the air pumps had to be driven by steam, the cost of primary motive power would be increased owing to the high cost of coal—$8 per ton in Switzerland. Nevertheless, for the extensions the company contemplates primary steam power, which is also used at Nantes and Nogent, and admits of the engines, the pumping accumulator, and loading station all being in one central station, thus admitting of a better organization, and compensating in part the extra cost by saving the expense and loss of power due to the turbine transmission and compressed-air main of the present installation. It may, however, be averred that as primary power for such compressed air installations, gas engines actuated by town or Dowson gas might be more economical than steam.

The cost of working the Berne line is compared, in the annexed table, with some other tramways worked under similar conditions by horse and mechanical traction for the year 1891. As is seen, both in the case of compressed air and of electric traction, the cost of working is considerably increased where steam at a high cost of fuel has to be used instead of hydraulic power. Given the latter, the cost of working by air is about the same as that by steam locomotives or steam cars; but over both of these last-named, compressed-air offers, at equal cost and for such short lines with constant traffic, certain advantages:

1891.	Length of line. Miles.	Motive power.	Construction and equip't, per mile, $.	Operation per car-mile, cts.
Geneva, city	8.68	Horse.	60,800	10.4
Zurich, city	5.58	Horse.	80,700	11.6
Geneva, suburban	40.30	Steam locomotive.	82,000	13.2
Mulhouse, city	18.00	Steam locomotive.	22,400	17.8
Montreux, suburban	6.82	Hydro-electric.	20,800	10.4
Florence, suburban	4.96	Steam-electric.	82,000	20.0
Tours, suburban	6.20	Steam cars.	10,200	17.2
Nogent (Paris), suburban	7.44	Steam-compressed-air.	46,100	25.6
Berne, city	1.86	Hydro-compressed-air.	48,950	17.8

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Compressed Air Motors at Berne.

In *Engineering* some interesting particulars were recently given of the Mekarski compressed air railway, at Berne, Switzerland, one of the few street railways in Europe operated by compressed air. The line at Berne is two miles in length, and the rails, which weigh sixty-six pounds to the yard, rest on gravel foundation or on concrete where the soil is loose. Seven motor cars are used, running on a ten minute headway, and the average speed, including stoppages, is six miles per hour. Each car has a carrying capacity of twenty-eight passengers. The fares are at the rate of two cents per mile, and gross earnings in 1891 amounted to 21.4 cents per car mile, of which sum the working expenses amounted to 83 per cent. The cost of motive power per car mile is given as follows: Wages, 5.86 cents; power station (water power), 3.72 cents; renewals of plant and motor, 1.86 cents; sundries, .3 cent; total, 11.74 cents. The maximum pressure used is 440 lbs. per square inch.

EN 11-9-93

A compressed air tramway, worked apparently on the Mekarski system, is to be built from the Louvre to Versailles and St. Cloud, in Paris, and also on a connecting line now building from the St. Augustin Church to Vincennes. On the first named line the motor will weigh 18 tons and work with air stored under a pressure of 1,000 lbs. per sq. in. This motor is to draw two of three cars carrying 50 passengers each, or more in a rush of traffic.

EN 4-26-94

A compressed air street car, designed by Mr. John Boyd Thacher, of Columbian Exposition fame, has been built at Albany, N. Y., and is to be tried in a street railway at Washington, D. C.

EN 8-16-94

The Mekarski system of compressed-air motors for tramway service has been adopted on three lines in Paris operated by the General Omnibus Co., and these lines are among the most important in their system. The longest runs are from the Louvre to Sevres and Versailles, about 12 miles. The two others run to St. Cloud from the Louvre, 6.3 miles, and from the Cours de Vincennes to St. Augustin, 5.7 miles. Trains of three cars, carrying 51 persons each, will start from the Louvre every 15 minutes. The motor-car will have six wheels coupled and will weigh 18 tons each, as an incline of 1 in 23 has to be mounted on the Serves line. Each of the three cars loaded weighs eight tons. The air-pressure used will be 1,138 lbs. per sq. in., and the reservoirs will have a capacity sufficient for a 12-mile run.

EN vol XXXI no. 22

A Mekarski compressed air car is being tested on the Woronoco Street Ry., at Westfield, Mass. It carries 300 lbs. initial pressure, and can run eight miles before the pressure is reduced to 100 lbs. This system is in use in Europe, and has been described in our columns. It is being introduced here by the Mekarski American Compressed Air Motor Co., in which Mr. James F Lewis and Addison C. Rand are interested.

EN 7-12-94

Three Mekarski compressed air street cars have been running in Westfield, Mass., for about a month and are reported to be doing good service and giving excellent satisfaction. On July 4 a very heavy traffic was carried, from 40 to 74 people per car, but the round trips, four miles in length, were made without interruption or difficulty. As announced in these columns some time ago, this system has been taken up by a company organized by Messrs. Jas. F. Lewis, of the Rand Drill Co.; Mr. C. B. Johnson, President of the Wilson & Baillie Mfg. Co., of Brooklyn, and other well-known men.

EN 12-27-94

Street railway motor cars operated by compressed air on a modification of the well-known Mekarski system, have been in service at Westfield, Mass., for several months, experiments having been made with a view to materially reducing the weight of the car without reducing its efficiency, and the desired results promise to be obtained. As a result of the practical experiments the American Compressed Air Motor Co. has been incorporated in New Jersey, with a capital stock of $250,000. Among the incorporators are John Fritz, of Bethlehem, Pa.; J. F. Lewis, of Chicago, Ill.; Addison G. Rand, of New York city, and E. W. Dickeman, of Westfield, Mass.

CHAPTER IX

TRANSMISSION OF POWER BY COMPRESSED AIR

COMPRESSED air has been employed in engineering operations for a long period, but it is only recently that its capabilities have been adequately recognised. The earliest important application of compressed air was for diving. Diving-bells are believed to have been used in the sixteenth century, and Smeaton in 1786 and Rennie in 1812 used them in important undertakings. Cubitt employed compressed air in sinking the piers of Rochester Bridge in 1851, and Brunel used a similar method at Saltash in 1854. Compressed air was used in driving the Thames Tunnel by Brunel, and Barlow employed it in the Thames subway. It has been largely used in tunnelling operations since that time. The shaft of the Marie colliery at Seraing was sunk by means of compressed air by the Société Cockerill in 1856.

The use of compressed air in transporting goods was suggested by Medhurst in 1810 and Vallance in 1818. Some early pneumatic railways were built. Similar methods have been adopted in recent years for transmitting messages and parcels in London and Berlin.

Papin seems to have considered the transmission of motive power by a vacuum method in 1688. Triger transmitted motive power by compressed air a distance of 750 feet at the mines of Chalonnes in 1845. Soon after compressed air was used in several collieries. The greatest impetus to the application of compressed air for transmitting power was due to its adoption for working the boring machinery at the Mont Cenis Tunnel. M. Sommeiller, in association with M. Kraft, made extensive experiments on compression at the Cockerill works at Seraing. On data so obtained the whole of the machinery for compressing, transmitting, and utilising compressed air at Mont Cenis was designed and constructed at Seraing. At first a kind of hydraulic pneumatic ram was used for compression. In 1861, this was superseded by water-piston compressors driven by turbines. The air was transmitted a maximum distance of 20,000 feet to work the drills.

The air pressure used was seven atmospheres (105 lbs. per sq. in.). There were at Mont Cenis air motors worked expansively, the cylinders of which were heated externally to prevent freezing. In the construction of the St. Gothard Tunnel, in 1872, still more powerful air-compressing machinery was employed. The compressors were at first designed to be of small size, to run at a high speed, and to be cooled externally. But with a short stroke and quick speed there is not time for the heat developed by compression to be abstracted through the cylinder wall, and a spray injection suggested by Professor Colladon was added.

In 1877 Mekarski used air compressed to twenty-five or thirty atmospheres in conjunction with a small amount of high-pressure steam to drive tramway cars, and Mekarski was one of the first to use compound compressors.

In 1877 at Vienna and in 1881 at Paris, M. Popp installed a system for working and regulating a great number of clocks, by impulses of compressed air conveyed in pipes from a central station. A demand arose for a supply of the compressed air for working small motors, and this proved so successful that there has been developed in Paris the most important system of power distribution hitherto carried out. In Paris, motive power is transmitted to industries of every kind over a large area by air compressed at a central station, and even sub-stations for electric lighting are driven by air motors. It is interesting that in Paris a system of distributing motive power by vacuum, carried out by M. Boudenoot, has been successfully in operation since 1885. The motors are worked by atmospheric pressure, and exhaust into pipes in which a vacuum is maintained by air pumps at a central station. A system of pumping sewage at a number of scattered sub-stations by compressed air, supplied from a single compressing station, has been developed by Mr. Isaac Shone, and is in operation at several towns in this country and the United States, and at Rangoon.

Compressed-air transmission is a perfectly general method of distributing power for all purposes. Whether in any given case it is the most advantageous, the least wasteful of power, or the cheapest in working cost, depends on various circumstances. M. Hanarte believes that it is and will continue to be the most economical method of transmission to considerable distances.[1] The loss in the air mains is very small. The motors worked expansively are efficient. The mains can be carried by any path, and differences of elevation between the compressing and working points do not sensibly affect the result. In hydraulic transmission the water must be collected, stored, and in some cases filtered, and having actuated a motor, means must be found for removing it. But air is everywhere available, and can be discharged anywhere without causing trouble. Compressed air has peculiar advantages in the case of underground transmissions. It has been used to replace manual labour in situations where hardly any other motive power could have been employed. In driving a tunnel at a mine at Sacramento, for instance, the cost was reduced to one-half, and the rate of boring was three times as fast when compressed-air machinery replaced hand labour. In such cases the advantage is so great, even with uneconomical machinery, that the inducement to adopt very perfect machinery is absent. Hence much of the air-compressing plant at mines has been unnecessarily inefficient and wasteful of power. In many cases air-compressing plant has been driven

by water power, and this also has tended to a neglect of the conditions necessary for economical working. Mr. Savage argues, with reference to the Terni Steel Works,[2] that the common objection to the use of compressed air on the ground of waste of power loses much of its force when the compressors are driven by an almost costless supply of natural energy such as water power. It is unfortunate for the reputation of the system of transmission by compressed air that the rough purposes to which it has been applied, the indifference to waste of power in mining and tunnelling operations, and the preference for simple and cheap machines, have delayed and hindered the improvement of compressed-air plant.

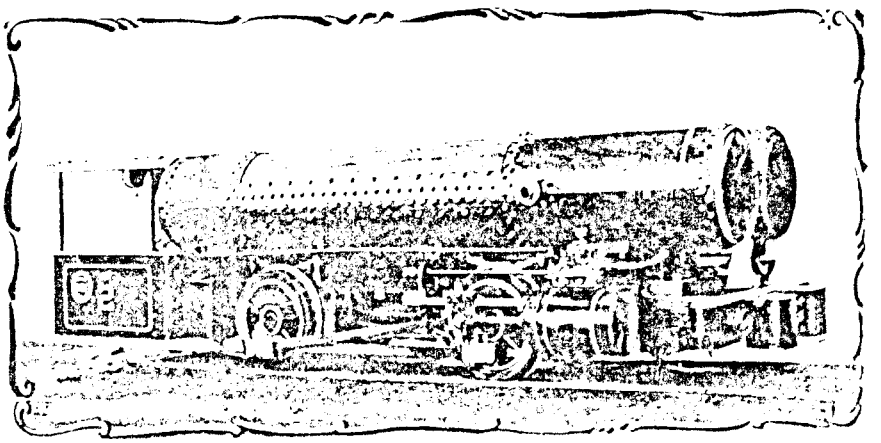
[1] 'Transmission du travail à distance par l'air comprimé'; *Congrès International de Mécanique Appliquée*. Paris, 1893.
[2] 'Terni Steel Works,' Savage; *Proc. Inst. Civil Engineers*, vol. xciii.

THE USES OF COMPRESSED AIR

WITH ILLUSTRATIONS

ADDISON C. RAND

NEW YORK
THE REPUBLIC PRESS



THE COMPRESSED AIR LOCOMOTIVE.

COMPRESSED AIR LOCOMOTIVE.

COMPRESSED AIR offers a valuable motive power in mines where the conditions of ventilation make it inexpedient to use steam. Mines which are already supplied with compressors for ventilation can readily adapt their existing plant to the pressure required by air locomotives. A pressure of from 400 or 500 pounds to the square inch is commonly used. A compressed air locomotive is, in fact, but a storage tank on wheels, with engines equipped to convert the tank pressure into direct motion of the wheels.

The tank is made of steel, with seams double and treble riveted. If there is any danger that the locomotive cannot carry sufficient power to perform the services required, arrangements can easily be made to "replenish" the tanks at stated parts of the route, by drawing air in small pipes from the distant storage reservoir at the compressors. By this simple and convenient means compressed air can be conducted long distances with very slight loss of power.

The dimensions of the locomotive illustrated herewith are: Gauge, 3 feet; cylinders, 8 inches by 12 inches; drivers, 24 inches; weight, 15,820 pounds. Dimensions of reservoirs, R. S. 23¾ inches by 15 feet 0½ inches; L. S. 23¾ inches by 10 feet 3¼ inch. Reservoir pressure, 600 pounds per square inch; working pressure, 100 pounds per square inch.

STREET RAILWAY CARS OPERATED BY COMPRESSED AIR.

FOR some time compressed air has been successfully used as a motor for street railways in Nantes, France, at Nogent near Paris, and Berne, Switzerland, the air compressors at the latter place being operated by water power. Each motor carries a storage pressure of 350 pounds at Berne, and 2,000 pounds in the line recently established in the city of Paris itself. Other lines carry varying pressures between these figures. The Nogent line traverses narrow and much travelled streets, sharp curves and grades. Under these conditions the most apparent features of the Mekarski compressed air system there used, are high speed when desired, absolute control of the car, an abundance of power, and silent action.

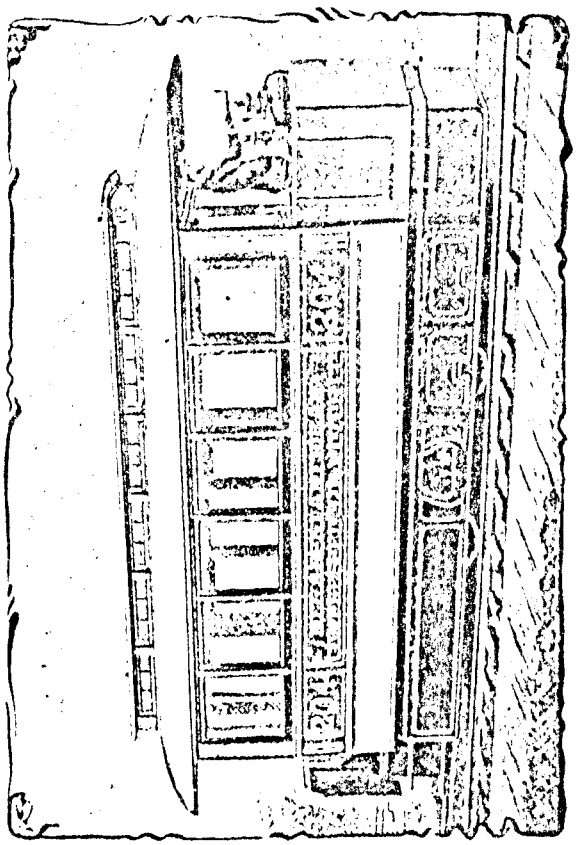
In any discussion of the street railway motor problem, it must be admitted that while much progress has been made during the last few years, yet a perfectly satisfactory system has not yet been found, especially for lines not doing enough business to warrant the erection of the overhead system of conducting the power.

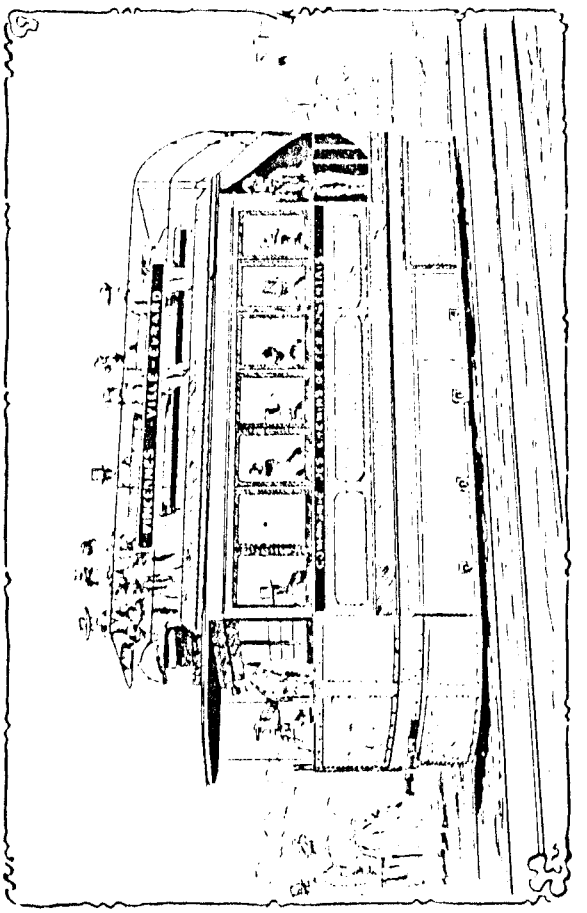
While it is true that all eyes are turned to electricity to solve the problem it is more than likely that another agent may be found to be more economical and reliable.

The cable car system represents an immense outlay in preparation, and constantly subjects the passengers to a distressing, jerky motion. The demand, however, for a system which is inexpensive and satisfactory, is increasing with the enormous expansion of towns into cities, all over the country.

By the compressed air system cars are handled easily, and quickly; the speed varies at will, from three to twenty-five miles; stops can be made on grades and curves without difficulty in starting again; there is no danger, odor, noise, or other discomfort. This system is in successful use abroad and meets the approval of all citizens in the cities and towns in which it is used.

Some work has been necessary in order to adopt it to American roads, and with these changes it seems likely to prove very useful.





COMPRESSED AIR STREET CAR, NOGENT, FRANCE.

EN 1895 vol 2

SRJ 8-95

THE POPP-CONTI COMPRESSED-AIR CONDUIT SYSTEM FOR STREET RAILWAYS.

A low-pressure, compressed-air system of traction for street railways, in which the car reservoirs are automatically recharged at intervals along the line has recently been tried in Paris, and with such satisfactory results, according to "La Revue Technique," that the municipality of St. Quentin has given a concession to the company owning the system. The system is the invention of Mr. Victor Popp and Mr. James Conti, the former being well known in connection with the Popp system of transmission of power by compressed air at Paris, as described in our issues of Dec. 14 and and 21, 1889.

At the power station the air compressors charge storage reservoirs from which the supply main is charged, a governor being used to maintain a constant pressure in the main. The main is laid underground between the tracks, and has branches at intervals to the charging apparatus placed in vaults between the rails of each track. To charge the car, it is stopped over the hinged covers of the vault, one of the wheel flanges depressing a hinged tongue placed against the rail, and this tongue operates a valve, causing the air pressure in the main to force up a blade or feeder carrying two small valves. This blade engages with a special joint on the car, entering between two rubber lips. As soon as the car is stopped, by the operation of a cock on the platform, the two lips are inflated, making an airtight joint between the car and the blade, or feeder, while at the same time the operating crank handles on the platform are disconnected. The feeder is hollow and fitted with valves which, when operated by the pressure of the air remaining in the car reservoirs, open communication between the supply main and these reservoirs. In a few seconds the reservoirs are charged, the crank handles are automatically connected and a whistle signals the car driver to close the cock, when the lips of the joint relax and free the feeder. As the car moves on the spring tongue rises to its original position against the rail head, causing the feeder to descend into the vault, the covers dropping down level with the street surface. The apparatus at any one vault can be thrown out of operation for inspection or repairs without affecting the rest of the system.

The car body is carried on an iron truck frame with four wheels, having plate springs over the axle boxes, while the body rests on four plate springs placed at the ends of the truck frame. The two axles are connected by coupling rods. The motor is a two-cylinder compound engine, with variable expansion, placed under the middle of the car and driving the end cranks of a short shaft carrying a pinion which gears with a spur wheel on one of the car axles. The slide valves are driven by eccentrics on return cranks, and the engine can be worked as a simple engine when required. The air is heated before entering the smaller cylinder, and again before entering the larger cylinder, the heater having a small coke fire, fed by a hopper, which only requires to be attended to once a day. The reservoirs, heater and all the machinery are under the car and the platforms are unobstructed. The car can run in either direction.

Compressed Air Motors in New York.

Much interest has been excited within the last week or two by announcement that the Metropolitan Street Railway Company intends to try on its Ninth Avenue line a compressed air motor, and had given orders for motor cars. Rumor was not exactly correct, but compressed air motors are to be tried on the Ninth Avenue line and perhaps on some others in this city. Most engineers remember a large number of so-called compressed air motors. Since the time of the late Horace Day compressed air has been the subject of many experiments as a motor on street railroads, with results which have not been, on the whole, satisfactory. At the present time, with economical compressors in the market and moderate-sized engines producing a horse power for 12½ to 14 pounds of water, there are more reasons to believe that compressed air motors will be more successful. The advent of cheaper and stronger steel tubes is also in favor of the project.

The General Compressed Air Company has undertaken the experiment.

EN 1-2-96

LETTERS TO THE EDITOR.

Compressed Air Locomotives; New Orleans & Western R. R.

Sir: We have to-day thoroughly tested our compressed air locomotives, special cars and track system at our extensive terminals at Port Chalmette, and now state that the same are an unqualified success.

We handled as much as 80 tons over a space of 6,000 ft., 2% grade, maximum curves of 75 ft. radius, and as a test, took a train of 80 tons throughout our yards, starting with 485 lbs. pressure and losing but 5 lbs. the entire distance.

The saving of labor is very large, and fire risks around the cotton sheds, cotton compresses and sorting yards are reduced to the minimum by the use of my new system, using compressed air locomotives.

Respectfully yours, A. H. Swanitz,
Chief Engineer and General Manager, N. O. & W. R. R.
New Orleans, La., Dec. 16, 1895.

(The terminal system was described and illustrated in our issue of Nov. 21. The locomotives were built by H. K. Porter & Co., of Pittsburg, Pa.—Ed.

EN 3-19-96

FIG. 3.—COMPRESSED AIR LOCOMOTIVE HAULING A TRAIN LOAD OF 80 TONS OF COTTON UP A 3% GRADE.

COMPRESSED AIR LOCOMOTIVES; NEW ORLEANS & WESTERN R. R.

The use of locomotives operated by compressed air offers special advantages for handling large quantities of cotton, as at wharves, warehouses, etc., where the danger from the sparks and cinders of a steam locomotive and the sparking of electric motors, renders either of the latter methods of traction inadvisable. In our issue of Nov. 21, 1895, we illustrated and described the warehouse and terminal system of the New Orleans & Western R. R., at Port Chalmette, near New Orleans, La., where all the hauling and shifting is done by compressed air locomotives, and we illustrate this week one of the engines used, Figs. 1 and 2. We also show the engine hauling a train load of 80 tons of cotton up a grade of 2%, this latter view, Fig 3, being taken from a photograph furnished us by Mr. A. J. Swanitz, Chief Engineer and General Manager of the railway company.

Two of these locomotives have been built by H. K. Porter & Co., of Pittsburg, Pa., and are small four-wheel switching engines running on tracks of 36 ins. gage. Each engine has two cylindrical air tanks, one 15 ft. 2 ins. long, and one 17 ft. 2 ins. long. Both tanks are 31⅝ ins. inside diameter, built up of 9-16-in. shell plates, the longitudinal seams sextuple riveted, with inside and outside welt strips, and the circumferential seams double riveted. The tank heads are of 13-16-in. flanged steel, of dished shape, with manholes in the front heads. The working pressure in the tanks is 600 lbs. per sq. in., and this is reduced to 140 lbs. in the auxiliary reservoir by means of an automatic pressure regulator. The Stephenson link valve motion is used operating a plain D slide valve, and graduated to cut off equally at all points of the stroke. The general dimensions of these engines are as follows:

Gage	3 ft 0 ins.
Wheels, diameter	2 ft. 2 ins.
Journals	4¼x5½ ins.
Wheelbase	5 ft 3 ins
Weight in working order	24,500 lbs.
Cylinders	9x14 ins.
" center to center	4 ft. 5¼ ins.
" center to valve face	9½ ins.
Piston rod, diameter	1½ ins.
Guides	Single bar
Connecting rod, length c. to c	5 ft. 10⅛ ins.
Inlet ports	4x7⅝ ins.
Exhaust ports	1¼x7⅝ ins.
Slide valves, outside lap	5-16 in.
" max travel	2⅛ ins
" lead	1-16 in
Capacity of air tanks, total	163 cu. ft.
Pressure in tanks	600 lbs.
" in auxiliary reservoir	140 lbs.
Brakes	Hand lever brake
Tractive force per lb effective press. on piston	43.61 lbs.
Total tractive force with effect. press. equal to 4-5 of press. in aux. reservoir	5,000 lbs.
Total adhesive tractive power at 1-5 of weight on driving wheels	4,900 lbs.

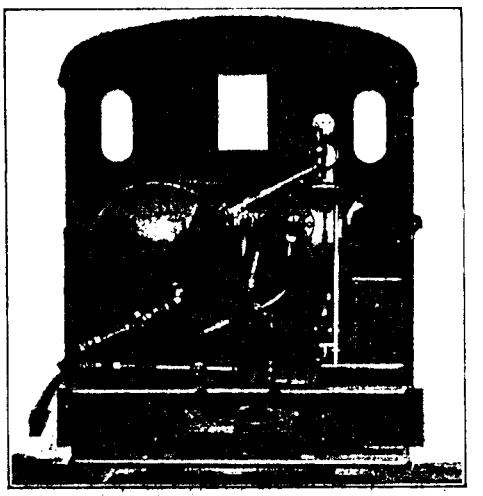


Fig. 2.—Rear View of Compressed Air Locomotive.

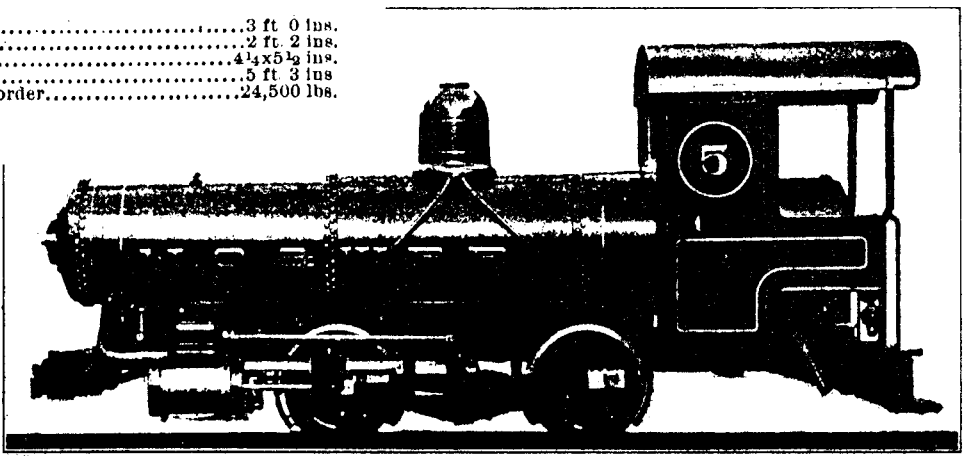


FIG. 1.—COMPRESSED AIR LOCOMOTIVE FOR NEW ORLEANS & WESTERN R. R.
H. K. Porter & Co., Builders.

Scientific American.

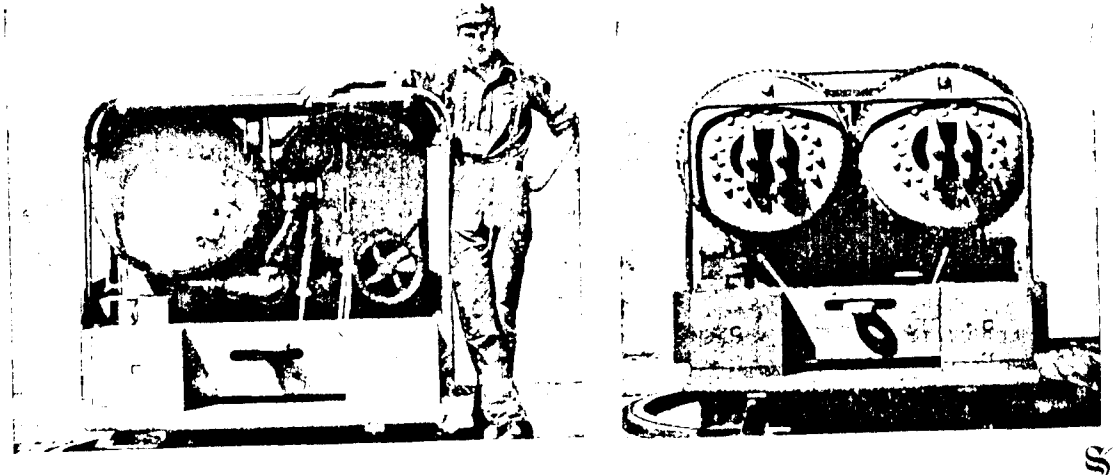
JUNE 6, 1896

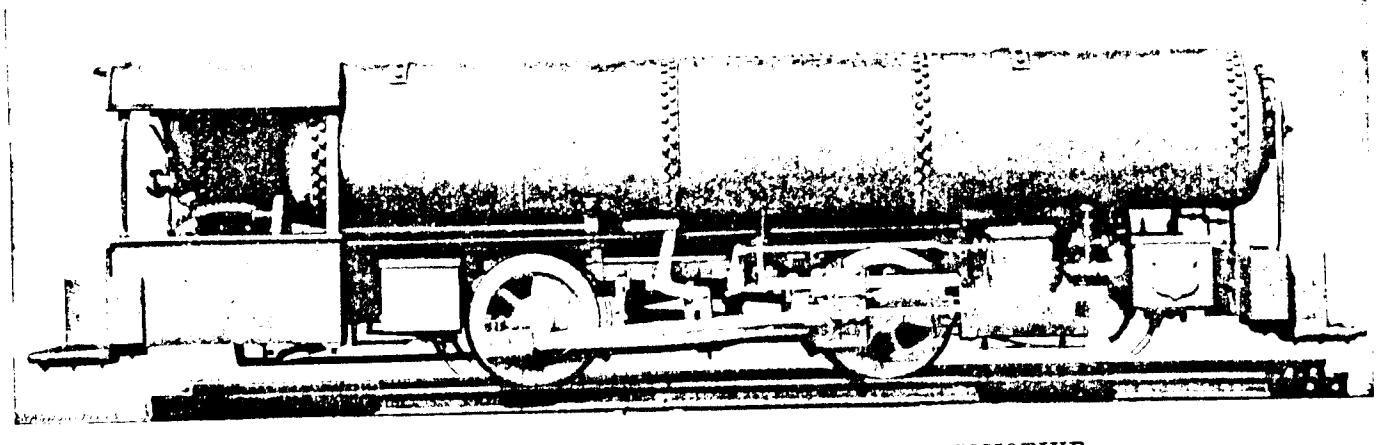
A DOUBLE TANK COMPRESSED AIR MINE LOCOMOTIVE.

The compressed air locomotive has a special field of usefulness in locations where it is necessary to take extra precautions against risk of fire, such, for instance, as powder mills and lumber yards and the great cotton wharves and warehouses of the South, or those coal mines which are infested with dangerous gases. In this respect it is greatly superior to the steam, or even the electric, locomotive; and, as compared with rope haulage, it has the advantage that it has greater mobility, and can be run independently over a wide area of sidings, etc.

The accompanying illustrations show a double tank compressed air mine locomotive, built by H. K. Porter & Company, Pittsburg, Pa., for the Susquehanna Coal Company, Glen Lyon, Pa. The dimensions are as follows: Cylinders, 7 inches diameter by 14 inches stroke; driving wheels, four-coupled, 24 inches diameter; weight, in running order, 18,500 pounds; length over all, 17 feet 6 inches; width, 5 feet 2 inches; height, 5 feet. There are two tanks of 130 cubic feet combined capacity, and the charging pressure for doing full work is 600 pounds. The air for charging the locomotive is furnished by a three stage compressor, having 20 by 24 inch steam cylinders, with compression cylinders 12½ inches, 9½ inches and 5 inches diameter by 24 inches stroke, with a capacity of 275 cubic feet of free air per minute compressed to 600 pounds per square inch at 100 revolutions per minute. This capacity is more than sufficient for two locomotives. When supplying one locomotive the average speed of the compressor is about 40 revolutions per minute. The air is conveyed in a 5 inch wrought iron pipe to the bottom of the shaft, a distance of 1,000 feet, and a further 3,400 feet along the gangway. Along the gangway are three charging stations, provided with gate valves, which enable any section to be cut off. The 5 inch pipe, which has been tested to 1,500 pounds pressure, acts as a reservoir to the compressor, having a capacity of 580 cubic feet at 600 pounds pressure. The charging station consists of a cast tee on the main pipe, with a 1½ inch opening, provided with a gate valve and a flexible metallic joint. It takes one and one-half minutes to charge the locomotive, the pressure in the main being thereby reduced from 600 to 570 pounds.

The air is stored in two steel tanks which are located between the locomotive cylinders on a saddle, much after the manner of a steam boiler. From them it is conducted to an auxiliary reservoir, eight inches in diameter, placed below and between them. In this tank the pressure can be regulated anywhere from 30 up to 140 or 150 pounds as required. The air is re-





A DOUBLE TANK COMPRESSED AIR MINE LOCOMOTIVE.

ceed from the main tanks by a reducing valve which can be regulated to any pressure at a moment's notice, and when once set, it maintains a constant fixed pressure in the auxiliary reservoir, thereby preventing any undue waste of air by injudicious handling. In case only light loads are to be handled, the pressure can be materially reduced in the auxiliary reservoir, or, on the other hand, in emergencies almost any pressure can be at a moment's notice utilized, and this without any undue heating or loss. In the auxiliary reservoir the air is controlled by a differential throttle, admitting the air to the cylinders.

The gage of the track is 36 inches, and the average grade is 1·07 per cent and the maximum grade 2·8 per cent in favor of the loaded cars. The locomotive hauls trips of 16 empty cars of about 2,500 pounds weight from the foot of the shaft, 3,700 feet, into the gangway, and trips of 16 loaded cars each with about 6,700 pounds of coal back to the shaft, with one charge of air, starting with a pressure of 575 pounds and ending with a little over 100 pounds. The heaviest work is hauling the empty trip up grade. The weight of each empty trip of 16 cars, including the locomotive, is about 60,000 pounds, and of the loaded trip, including the locomotive, 166,000 pounds. The locomotive will make from 25 to 50 miles per day, depending on the length of the run and the time required for making up trips.

The cost of operation of this plant has been found to vary from one to one and one-half cents per ton mile, including all expenses, interest and depreciation of plant, varying with the character of the rolling stock used. The depreciation on the locomotive is very low, there being no boiler to wear out; and the tanks, having nothing to corrode them, should, if kept well painted, last almost an indefinite period. In this case the condition of the car wheels, owing to spragging, was bad, there being many flat spots caused by sliding, and the frictional resistance per ton on the track was excessive. These cars are gradually being equipped with self-oiling wheels and a better form of brake. When this change is completed, it is expected that the cost of haulage by this system will be still further reduced.

Scientific American.

[JUNE 6, 1896.

PROPOSED EQUIPMENT OF THE NEW YORK SURFACE ROADS WITH COMPRESSED AIR MOTORS.

The Metropolitan Traction Company, which controls altogether about 132 miles of street railway in this city, and carries daily upward of 650,000 passengers, is contemplating an important change in the motive power of a large portion of its lines. About 32 miles of the system are at present operated as cable and underground trolley lines, and the plant is of the latest pattern and thoroughly up to date; but the greater part—fully 100 miles of the lines—is still worked by the slow and objectionable horse car. Several months ago the company determined to abolish the horse car and introduce in its place some form of mechanical traction, and in the interval their agents have been making an exhaustive examination of the many systems of street car traction which are being operated in Europe and America.

It has been determined to make a thorough trial of a compressed air motor which has been designed by Joseph H Hoadley, of the engineering firm of Hoadley Brothers, who is now associated with the American Wheelock Engine Company, of Worcester, Mass. We are informed by the Metropolitan Company that at a private trial recently had at the Worcester works before the engineers and officials the Hoadley motor showed a remarkable efficiency, as compared with any compressed air motor which they had previously subjected to trial. At present ten of the company's cars are being equipped with the new motor, and if they prove as successful in service as the experimental car which was recently tested, it is likely that all the existing horse car roads will be similarly equipped.

The air will be carried in two cylindrical steel tanks placed between the trucks and beneath the floor of the car, and they will be charged at an initial pressure of 2,000 pounds to the square inch. The power house at 147th Street and Lenox Avenue will contain a 500 horse power Greene-Wheelock engine and a Minerva air compressor, the reservoir capacity of the plant being 5,000 cubic feet. The compressed air motor is being adopted in preference to trolley or cable traction, not merely from motives of economy, but also with a view to securing a service which shall be free from the interruptions to which the cable and trolley systems are liable.

The operation of these cars will be watched with close attention, not merely by the company which is making the experiment, but also by the engineering world at large. Engineers in the United States have been so fully occupied with the development of electric traction—and it has had a growth and a success which is phenomenal—that comparatively little attention has been paid to other methods of traction which utilize the oil, gas, and compressed air motor. As compared with the cost of the electric and cable systems, the compressed air and gas motors which are being increasingly used in European cities are said to be showing remarkably economical results. Chief Engineer Pearson, of the Metropolitan Company, is now in Europe for the purpose of personally inspecting the working of some of the more important plants that are operated on the above systems.

On another page will be found a description and illustrations of a compressed air locomotive, which has proved very successful in the mines of the Susquehanna Coal Company, Glen Lyon, Pa. The chief engineer of the company, Mr. J. H. Bowden, states that the cost of operating this plant is between 1 and 1½ cents per ton per mile, and that, with the introduction of a better type of coal car, he expects to make a still more economical showing.

Compressed Air Motors for New York.

The Metropolitan Traction Company has decided to test the value of compressed air motors for traction, and ten cars will soon be in service on one of its lines at the upper end of the city. The motive apparatus will be supplied by the American Wheelock Company, at whose works in Worcester, Mass., the equipment of the cars is now being carried on. Owing to the ample capital of the Wheelock Company and the engineering ability of its engineers, the test promises to be most interesting and one which will determine the value of compressed air for this class of work.

EN 1896 vol vi

The Efficiency of the Compressed Air Power Plant At Grass Valley, Cal.

Sir: After about three months working of the water-power and compressed air-transmission plant, described in your issue of Dec. 19, 1895, I am able to give the following figures with reasonable assurance of their accuracy.

The reheating of the air is found to cost almost precisely 1 ct. per day per horse power (theoretical) of the water used, or 1 1-3 cts. per day per HP. of work actually done by the motors.

The following efficiencies do not include the above cost of reheating:

Efficiency of compression and transmission from water-wheel to motors.....79.5%
Efficiency of compression and transmission from the theoretical power of the water to the motors....74 %
Efficiency of compression and transmission to and through motors 71.6%
Efficiency of compression and transmission from the theoretical power of the water to and through motors..... .....66.6%

Putting it in plain English, we have 304 theoretical HP. in our water and we obtain 202.7 HP. of work actually done at the mines. The efficiency of the water-wheel is a trifle over 90% at all loads from one-fourth to full. Very truly yours, etc.,

Grass Valley, Cal., April 9, 1896. A. D. Foote.

SRJ 1896 vol 12, no. 7

Experiments With Compressed Air on Lenox Avenue, New York.

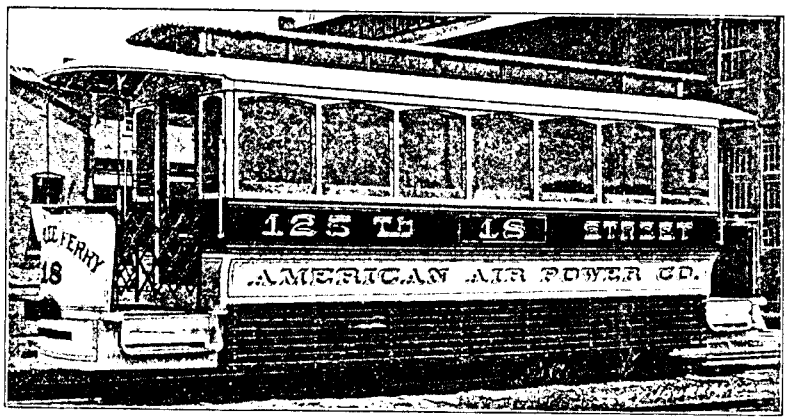
The announcement was made last month that the Metropolitan Street Railway Company, of New York, would install on its Lenox Avenue system during the first part of July ten compressed air motor cars built at the plant of the American Wheelock Engine Company, Worcester, Mass. The trial with compressed air is in the nature of an experiment to determine whether this motive power is desirable for use on the many crosstown lines of the company, and does not indicate that the electric conduit system which has been in operation on the Lenox Avenue line during the past year has been unsatisfactory. The problem of the best motive power to use on its horse car lines, now aggregating about 150 miles in length, is an important one, and the policy of the company as outlined by the managers is to spare no effort to determine the best possible substitute on these lines for animal power.

The compressed air motors, it is claimed, will employ some novel principles which will eliminate to a large extent, if not entirely, many of the defects which have appeared inherent to the employment of this power in the past. The company which will manufacture these motors is said to be a particularly strong one both in financial resources and engineering ability, and includes among its corps of engineers, J. H. Hoadley, of Hoadley Brothers, New York, and Walter H. Knight, formerly chief engineer of the General Electric Company, and now chief engineer of the new air power company.

SRJ 1896 vol 12, no. 7

Compressed Air Motors on 125th St., New York.

The announcement was made last month that the Third Avenue Railroad Company, of New York, would make a test this summer on its 125th Street line, of two compressed air motors built by the General Compressed Air Company. One of these cars has just been completed at Rome, N. Y., and is shown in the accompanying engraving. It measures twenty-eight feet over all and weighs about 18,000 lbs. with mechanism. The air is stored under a pressure of 2000 lbs. per square inch in reservoirs, sixteen in number, carried on the truck and having a total capacity of fifty-one cubic feet.



COMPRESSED AIR CAR.

The motor mechanism consists of two simple link motion, reciprocating engines with cylinders 7 ins. dia. × 14 ins. stroke, with valves cutting off at from one-tenth to one-sixth, and applying the power by connecting and parallel rods direct to the crank pins of the drive wheels. The latter are twenty-six inches in diameter, with wheel base of 7½ ft.

In operation the full reservoir pressure is not used, but it is lowered to 150 lbs. per square inch by a reducing valve. After leaving the reducing valve the air is heated to between 200 and 300 degs. by being passed through a hot water cylinder carried on the car, the object being to obtain more work from the air and also to avoid the production of extremely low temperatures in the air cylinder which would otherwise result from the expansion of the air.

The hot water tank is seven feet long and eighteen inches diameter and is charged at the power station before starting out. It is jacketed with non-conducting material to prevent external radiation.

The car is also equipped with air brakes.

SRJ 9-96

Compressed Air Motors in New York.

During the last month the three compressed air motor cars manufactured by the Rome Locomotive Works have been received by the Third Avenue Railroad Company and have been put in operation on the 125th Street line of that company. The car bodies were built by the Brooklyn & New York Railway Supply Company. The cars have not been in operation long enough yet to determine the question of economy.

The compressed air cars for the Lenox Avenue line of the Metropolitan Street Railway Company have not yet been received from the works at Worcester, Mass.

TRIAL OF THE COMPRESSED AIR MOTOR BY THE THIRD AVENUE RAILROAD COMPANY, NEW YORK.

The compressed air motor is a device which is suffering from the prejudice engendered by many years of costly but comparatively fruitless experiment. Invention and capital, seeing its promising possibilities, have frequently joined hands in the effort to produce an efficient motor, but beyond learning some valuable lessons as to the chief sources of loss, and the direction in which improvement must be sought, they have failed to produce an effective machine.

At the present writing, interest in the compressed air motor has been revived by rumors of its adoption by two large corporations: the Metropolitan Traction Company and the Third Avenue Railroad Company, both of New York City; the former making use of the Hoadley motor, and the latter adopting the system invented by Mr. R. Hardie.

The trouble with the earlier systems has been of a twofold nature. When air was compressed into the storage reservoir, a certain portion of the power was expended in raising the temperature of the air (according to the well known law), and this heat, which was subsequently lost by radation, represented a dead loss of power. Moreover, when the air was expanded in the cylinders, there was a corresponding reduction of temperature, which was often so great as to cause freezing and choking up of the exhaust passages.

In the Hardie system it is sought to prevent the first loss by compressing the air in three stages, and recovering the heat of compression by passing the air through tubes around which cold water is circulating. The cooling water is fed to the boilers and the heat which it has withdrawn from the compressed air is thus recovered. After passing the third stage of compression and cooling, the air is forced at a pressure of 2,000 pounds to the square inch into a reservoir consisting of a stack of rolled steel flasks, 9 inches in diameter and 20 feet long.

The cars, one of which is shown in the accompanying illustration, are similar in their general appearance to an ordinary street car; but they are provided with a truck whose construction is suggestive of the bar frame of a locomotive, the truck, moreover, being suspended by springs from the axle boxes, and the cars being similarly suspended from the truck. Underneath the seats and beneath the floor of the car are sixteen air reservoirs, similar to those in the power house. In the center of the car and also beneath the floor is placed a hot water tank, by means of which the air is heated before it enters the cylinders, and the difficulty of frozen exhaust passages is overcome. It is 18 inches in diameter and 7 feet long, and is filled with 500 pounds of water.

Before the car starts on its run, its air reservoirs are charged with cold air at 2,000 pounds pressure by means of a flexible tube connecting with the power house supply, and steam is admitted to the heater until its contents are raised to a temperature of 350 degrees. It takes a little over half a minute to charge the reservoirs.

In operating the car, the air is first expanded by a reducing valve to a pressure of 150 pounds, and passed into a receiving cylinder, whose capacity is one cubic foot. It is then admitted to the heater, where its action is thus described by General Herman Haupt, the consulting engineer of the company: "When the air passes into the tank of water heated to 350 degrees, each 50 cubic feet of air absorbs and carries over an amount of water in the shape of steam equivalent to 26 cubic feet of air. This adds 50 per cent to the volume; and, as the air is itself expanded 50 per cent by the increase of temperature, the total gain of volume as the air and steam pass from the heater is 100 per cent. The condensation of the steam in the cylinders and pipes liberates the latent heat and maintains the temperature at such a point as to render freezing impossible."

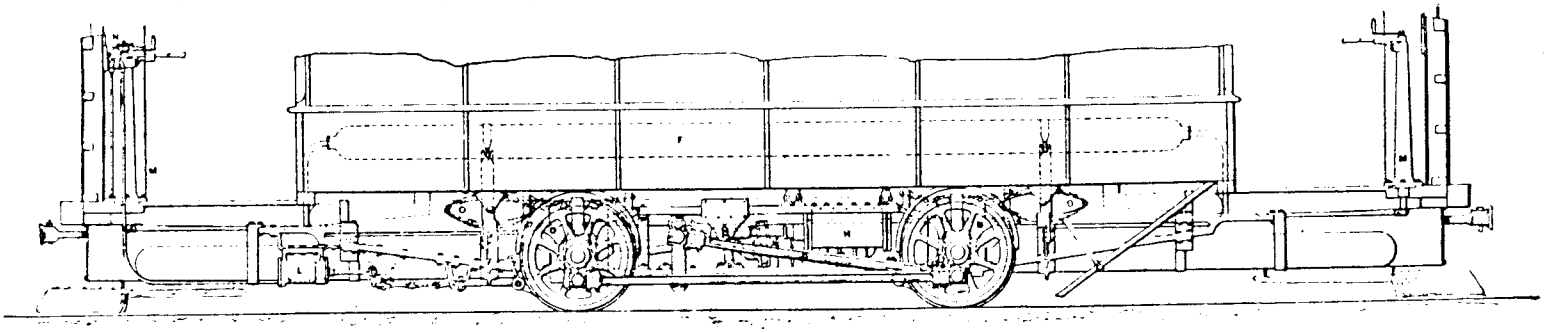
General Haupt informs us that the efficiency of the heater was tested on a couple of experimental runs, on the first of which, with the heater in use, 308 cubic feet of air were used. The heater was then emptied, and the same run was made with cold air, when more than double the amount, or 661 cubic feet, were required.

The two cylinders of the motor, 7 inches diameter by 14 inches stroke, are built into the frame on each side of the car, and lie inside the wheels. A short connecting rod from the cross head operates a vertical rocking lever, from which a connecting rod transmits the motion to a crank on the outside of the driving wheels. The two wheels on each side are connected by a coupling rod, so that the whole weight of the car is available for adhesion.

The valve gear is of the ordinary Stephenson link type, with an additional valve on the back of the main valve to regulate the cut-off.

The controller and "reverse lever" are situated as in an electric car on the front platform. The throttle valve is operated by a crank handle, and the reversing and cut-off are effected by the lever. There is another lever for working the air brake, by means of which also an auxiliary supply of air can be admitted to the cylinders at starting.

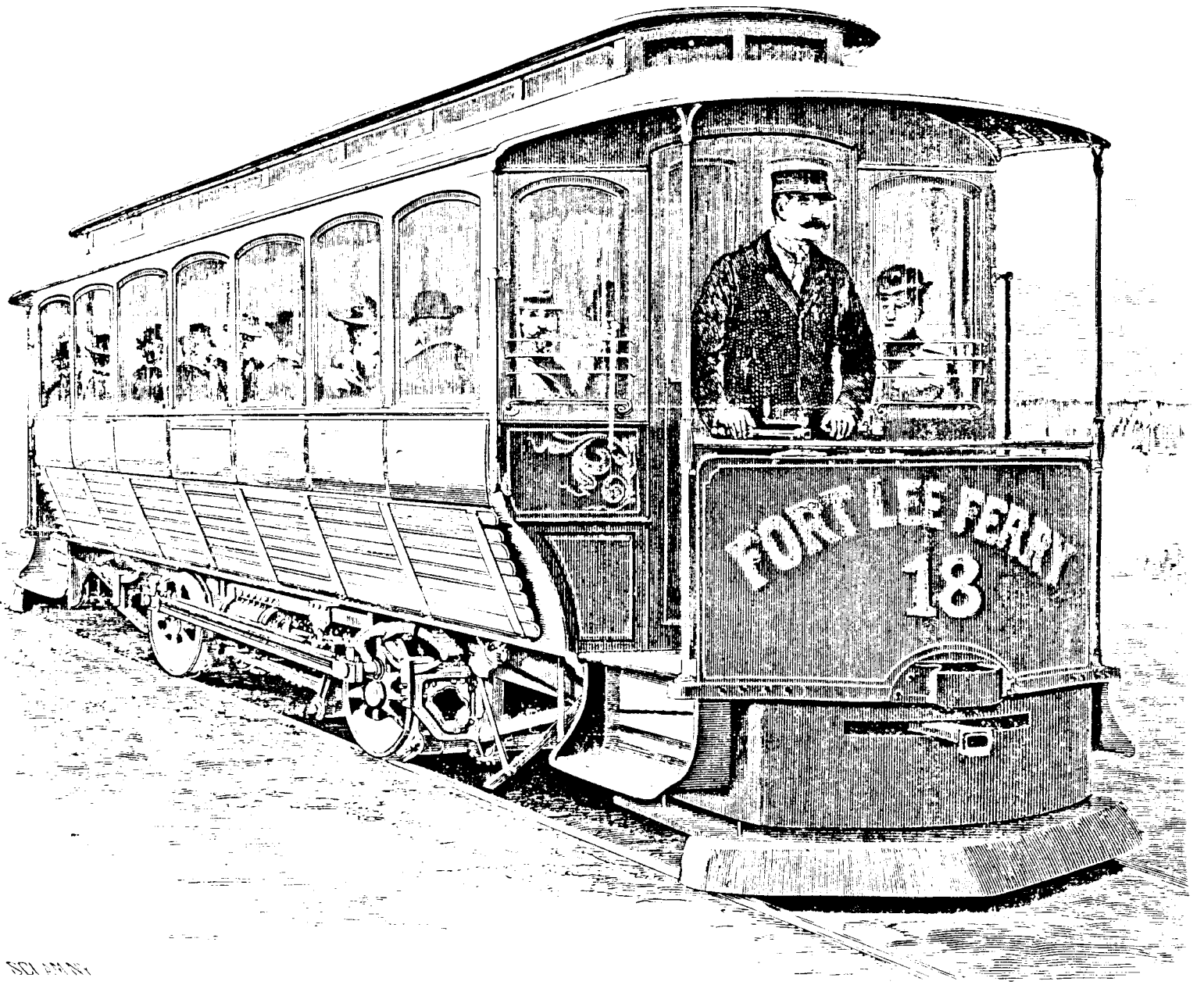
The reciprocating parts are counterbalanced, and this work appears to have been judiciously done, as there is no perceptible oscillation due to this motion. The general appearance of the car is pleasing, the moving parts being hidden from view by letting down the slat apron, which is shown in the illustration hinged back against the side of the car.



SIDE VIEW OF ENGINES AND AIR BRAKE, HARDIE COMPRESSED AIR MOTOR.

Scientific American

AUGUST 15, 1896



THE HARDIE COMPRESSED AIR MOTOR CAR.

COMPRESSED-AIR PLANT ON THE CONSTRUCTION OF THE JEROME PARK RESERVOIR.

The use of compressed air for power purposes and power transmission has had a very great and comprehensive growth within the past few years, and one of the most recent and interesting applications of this power is on the extensive contract work for the construction of the Jerome Park reservoir, for the water supply system of New York city. As the contract amounts to nearly $5,500,000, and will extend over about seven years, there was ample reason for carefully considering the comparative advantages and economy of different methods of supplying power for the drills, hoists, pumps, etc., to be used on the work, and as a result of this investigation it was decided to use compressed air, distributed to all parts of the work by pipe lines from a central power plant. This plant is operated by one engineman and one fireman. The main pipe lines will remain practically permanent during the work, the branches being shifted, and extended as required by the progress made in excavation. This system will undoubtedly effect a considerable saving in fuel and labor expenses as compared with the more common methods.

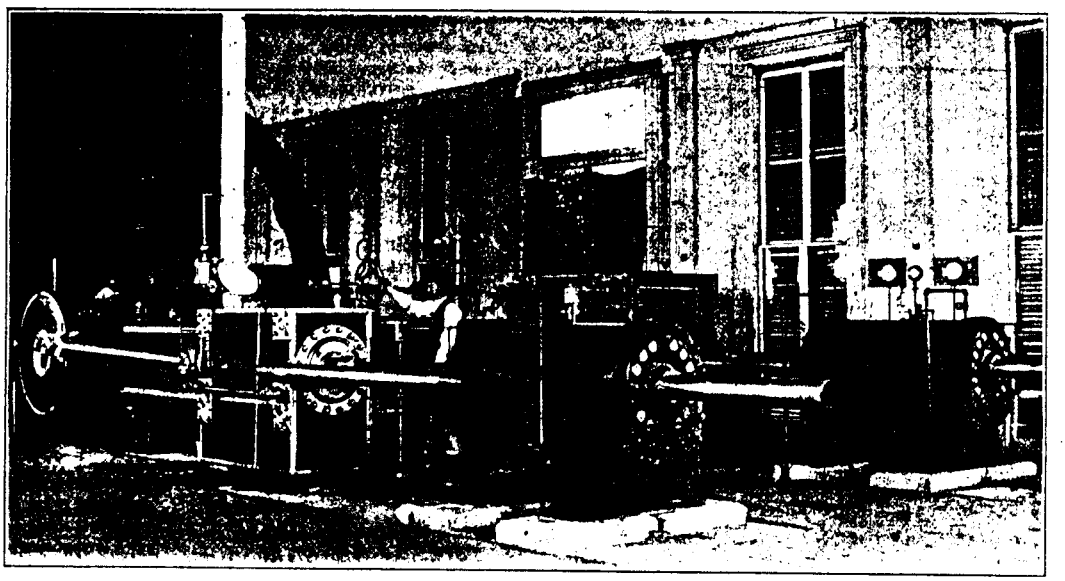


FIG. 1.—AIR COMPRESSING PLANT FOR THE WORK ON THE JEROME PARK RESERVOIR.

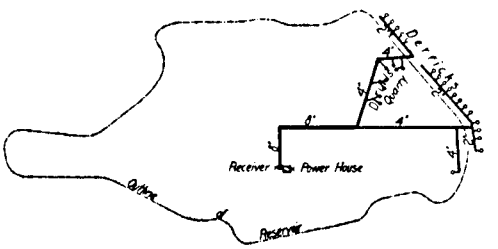


Fig. 2.—Sketch Plan of Reservoir Site, showing Location of Power House, Transmission Pipes and Working Plant.

On such construction work the general practice is to use steam power, with separate boilers for each one or two hoists, and other boilers near groups of drills. This practice is necessarily wasteful in fuel, as the amount of fuel used is excessive, the boilers not being adapted for or worked with a view to economical consumption, and much fuel being burned without doing any work during dinner hours and when the machines are stopped for any cause, while leaky joints and condensation in the long lines of pipes always cause considerable waste and trouble. Besides this a separate attendant is required for every boiler.

The Jerome Park reservoir, where this compressed air plant has been installed, was described in our issue of July 18, 1895. It is situated near Van Cortlandt Park, on the New York & Putnam Division of the New York Central R. R., about 11 miles from the Grand Central Station on 42d St., and 5 miles north of the Harlem River. It will cover about 300 acres of land and will have a capacity of 2,000,000,000 gallons. The construction will require about 4,000,000 cu. yds. of earth excavation, 3,200,000 cu. yds. of rock excavation, 150,000 cu. yds. of concrete masonry, 82,000 cu. yds. of brick masonry, 113,000 cu. yds. of rubble masonry and 250,000 sq. yds. of rubble masonry facework. The masonry includes heavy core walls for the embankments. The bids for the work ranged from about $5,000,000 to $13,000,000, and the contract was awarded in August, 1895, to Mr. John B. McDonald, of Baltimore, Md., and New York city, at $5,473,060. Preparations for commencing the work were at once started, and the work is now in active progress. At the present time about 550 men are at work, while the plant includes 8 narrow gage contractors' steam locomotives, 2 steam shovels, 18 derrick hoists, 10 drills and a number of wagons, teams, dump cars, etc. Besides this, offices, living quarters, stables and stores of all kinds of material and supplies have been established, as the work will last for about seven years, the date set for the completion of the contract being Nov. 1, 1902.

The contract for the air compressing plant was placed by Mr. McDonald with the Ingersoll-Sergeant Drill Co., of New York city, and this has now been installed and put in operation, having been started on May 14. For a power house, one of the large buildings of the club at the old Jerome Park racecourse is used; the building having been removed bodily to a convenient situation. In this are installed a cross-compound Corliss engine of 600-HP., with a compressing cylinder

behind each of the steam cylinders. The engine drives a flywheel 25 ft. diameter, weighing 50,000 lbs., mounted on a shaft 14 ins. diameter, the shaft having an eccentric keyed on each side of the wheel and being driven by means of a crank disk at each end. The main shaft bearings are 14 x 26 ins. The steam cylinders are 24 x 48 ins. and 44 x 48 ins.; while the air cylinders are 24¼ x 48 ins. The cylinders are 6 ft. apart, longitudinally, and 14 ft. c. to c. transversely. The walls of the air cylinders are cooled by water jackets. The compressor is of the company's standard design, which is probably familiar to most of our readers. The air enters the cylinder through a hollow tail-rod, and the piston has an annular disk valve in each face, the space between the open valve and its seat being about ¼-in. On the forward stroke the front inlet valve is closed and the air in front of the piston is forced through the front discharge valves as soon as the cylinder pressure exceeds the receiver pressure, while at the same time air is passing through the tail-rod and open rear valve into the space behind the piston. On the return stroke the rear inlet valve is closed and the air is forced through the rear discharge valves, while the air entering through the tail-rod passes through the open inlet valve in the front face of the piston and fills the forward end of the cylinder. This arrangement was shown and described in detail in our issue of Sept. 27, 1890. Each air cylinder is also fitted with a regulator or loaded relief valve by which the load is thrown off when the normal receiver pressure is exceeded owing to the air not being used. The normal pressure in this case is 75 lbs., and when it rises to 80 lbs. a passage is opened connecting both ends of the cylinder, so that the piston has an equal air pressure on both sides, both inlet valves being thus kept closed and the piston moving to and fro without doing any work. When the air pressure has fallen a trifle below 80 lbs. the regulator closes, and compression is then resumed. This device was fully illustrated and described in our issue of March 28, 1891. The cut-off of the steam cylinders is regulated automatically by the load, as in all Corliss engines. From the compressor cylinders the air passes to the receiver, which is a riveted steel cylinder or tank 5 ft. 6 ins. diameter and 18 ft. long, placed just outside the engine house.

The engine is intended to work as a condensing engine, but is not being so worked at present, and the connecting rod to the rocking lever of the condenser pump is disconnected. The reason for this is that there is not now a supply of water available for condensing purposes, but, of course, the engine cannot meanwhile work so economically in fuel consumption. The water for the boiler is taken from a well sunk near the engine house and a reservoir for the condensing water has been built. Steam is supplied by a single water-tube boiler made by the Hogan Boiler Co., of Middletown, N. Y., the boiler having three furnaces. The boiler is rated at 250 HP., and carries a pressure of 120 lbs. The entire power plant is handled by one engineman and one fireman. The engine and compressor were built at the works of the Ingersoll-Sergeant Drill Co., at Easton, Pa. This plant, shown in Fig 1, was started up on May 14, and later on, when a larger force is at work on the reservoir, it is intended to put in a duplicate plant, working the air cylinders compound.

Fig. 2 is a plan of the work, with an outline of the boundaries of the reservoir, and showing the positions of the pipe line, drills, hoists, etc., as at present existing. From the receiver an 8-in. pipe extends for a distance of 1,500 ft., and is followed by two main lines of 4-in. pipe, from which again run 2-in. pipes aggregating about 2,000 ft. in length. The branch pipes to the machines are 1½ ins. diameter, this being the smallest size used. The aggregate length of the piping system is now about 6,300 ft. Another 8-in. main is intended to be laid later, in a direction opposite to that taken by the present 8-in. main. All the pipe has screwed joints. There is one reheater on the 4-in. pipe line, this being of the Sergeant pattern, described in our issue of May 9, 1895. The heater is a truncated cone 3 ft. 6 in. in diameter at the base and 4 ft. 6 ins. high, the center of which forms a stove; the air enters at the top and passes down over the heating surface, the volume

FIG. 3.—GROUP OF DERRICKS OPERATED BY COMPRESSED AIR.

of air space increasing as the air expands, so that the velocity and friction remain practically constant. The use of this reheater is said to increase the efficiency 33% over work done by the same volume of air used cold. The air pressure is designed to be 75 lbs. per sq. in. at the compressor and 70 lbs. at the tools.

There are now in use 10 drills, 18 derrick hoists and 2 pumps. The drills are of the well-known Ingersoll-Sergeant make. The hoisting engines are of the Lidgerwood make, with two cylinders 7 × 10 ins. and double drums. In the building of the masonry core walls for the embankments a row of derricks is erected, each derrick being operated by a hoisting engine, but the booms are swung by hand by means of guy ropes. The masts and booms are sticks 14 × 14 ins., the masts being 65 ft. long, and the booms are 62 ft. long. The derricks have a lift of 57 ft., a working radius of 118 ft., and a hoisting capacity of 10 tons. The pumps are small horizontal pumps placed in the trenches for the core wall foundations.

Figs. 3 and 4 show two views of the work now in progress. The derricks are all operated by compressed air, and the rock excavation shown was effected by groups of drills operated by air. For photographs and other information used in this article we are indebted to the Ingersoll-Sergeant Drill Co., and to Mr. Henry B. Reed, C. E., who is superintendent for Mr. McDonald, the contractor.

COMPRESSED AIR MOTORS form the subject of a late letter from Paris to the New York "Evening Post.". The Mekarski system, introduced at Nantes, in 1879, includes the storage of air compressed to 25 atmospheres in reservoirs under the motor-car. This air passing through a regulator is reduced to a pressure of 5 atmospheres in the working cylinders, and the loss of energy in this reduction, estimated at 38%, is met by a reheating of the air before it enters the cylinders. The Mekarski system of motors is now used on the line from Nogent to Bry, on the Marne, from the Louvre to St. Cloud and to Versailles; and from St. Augustin to Vincennes. The objections to the system is the dead weight of the motor-car and its reservoirs, amounting to from 4 to 10 tons, and the necessity of going to a central station for re-charging. Otherwise, the system works well and grades of more than 6% are readily overcome. Mr. Popp, of the Compagnie Parisienne d'Air Comprime, now proposes to establish lines of piping carrying compressed air and so arranged as to charge the car reservoirs at short intervals along the route, and he has already laid down 2½ miles of such a line, furnishing air at 10 atmospheres, in Saint-Quentin. He would thus do away with the heavy reservoirs on the motor-car and claims a loss of only 1% in transmitting the compressed air 2½ miles, with a plant costing about the same as for electric traction; both for compressors as offsetting dynamos, and pipes as offsetting overhead wires and their supports. The extreme cost price of the Mekarski system, as originally used, is set down by this correspondent at 7 cts. per kilometer per motor car, or 11.3 cts. per mile, including the compression of the air, repairs, maintenance, interest, sinking fund and profit to factory. This is compared with 17.7 cts. per mile for horse-tramways in Paris. When the motor hauls another 50-passenger car, the supplementary expense is 3.2 cts. per mile. In Belgium, where labor and coal costs half as much as in Paris, the cost goes down to 6.4 cts. per mile for the motor-car.

FIG. 4.—EXCAVATION AND LOADING OF ROCK BY COMPRESSED AIR PLANT.

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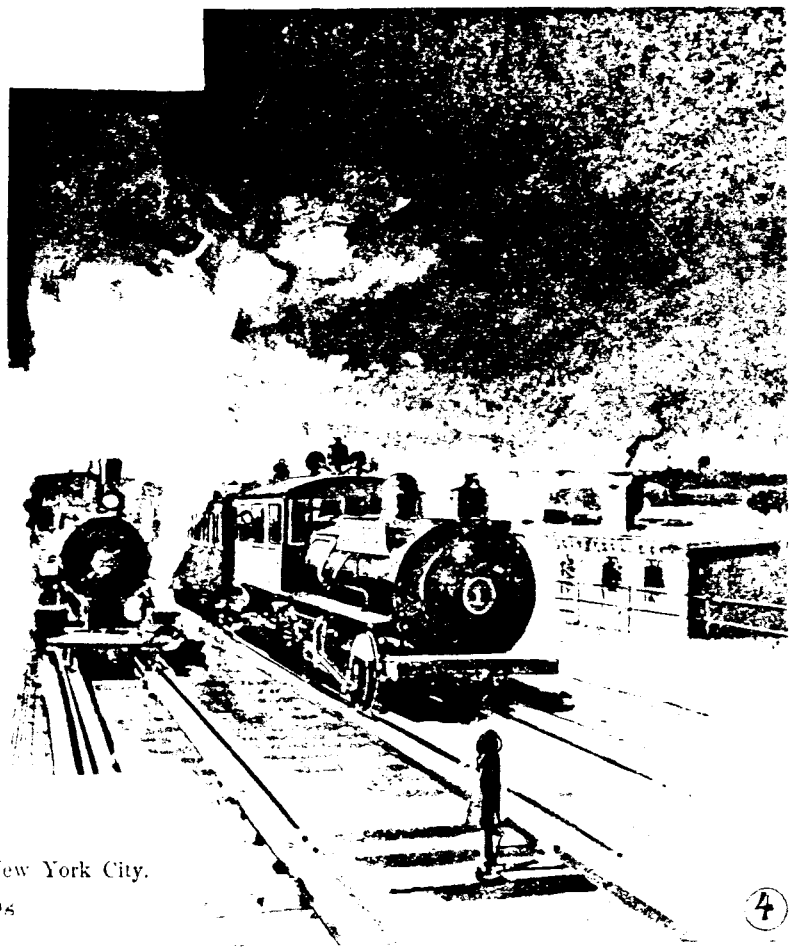
Compressed Air Motors in New York.

Several of the compressed air motor cars recently built at the Worcester works of the Wheelock Engine Company were received in New York last month. They were built under the superintendence of Joseph Hoadley, of Hoadley Brothers, and Walter Knight, formerly of the General Electric Company. A trial trip was made on Sept. 26, on the lines of the Metropolitan Street Railway Company with satisfactory results.



THE DIFFERENT USES FOR COMPRESSED AIR.

1. Car using the Hardie Compressed-Air Motor on 125th Street, New York City.
2. The Mekarski Compressed-Air System used in Paris—recharging *en route*. 3. Motor and Train in Paris (Mekarski System).
4. Compressed-Air Locomotive to be operated on the Elevated Railroad in New York City.

COMPRESSED-AIR MOTORS.

For the last three months, on the 125th Street surface line in New York city, two new cars have been in operation that offer a novelty in the way of street traction. They run without visible means of propulsion; there is neither overhead trolley, cable, nor conduit; they are very near to noiseless, they run smoothly, and start and stop without jerk or jar. These cars alternate with those propelled by cable, and, save in the smoothness of their operation, there is outwardly nothing to announce that they are unique. They have thus far covered 12,000 miles, and carried some 75,000 passengers, and this not so much without accident as without incident. They are a long stride toward the dream of the street-railway manager—an independent self-contained motor—and that they are successful means much. If the claims of economy are substantial, it is an allowable surmise that this is the traction force of the future in large cities, if not in small.

The new motors represent the latest phase of development in a very wonderful new power which has been rapidly coming into use in the last ten or fifteen years. That is compressed air. The remarkable powers of this force have been largely lost sight of in our modern flood of marvels. If, a hundred years ago, Franklin had made announcement of a way to bottle up the ambient atmosphere in steel flasks, or flasks of any sort, and to tuck these in obscure corners, and use the power resident in them for many and divers conveniences, there is hardly room for doubt that his discovery would have been regarded in that day every whit as extraordinary as his feat of drawing lightning from the clouds. And there are those of competent judgment who believe that if a tithe of the inventive and mechanical genius that has been employed in the development of electricity had been diverted to the perfection of appliances for the use of compressed air, the present relation of these two novel aids of industry would be very different, if not reversed. But electricity was mantled with the glamour of the unknown; for a long time there seemed no limit to its capabilities; it was being applied everywhere and in the most surprising variety of ways; and in the furor it created, compressed air found little favor beside its more brilliant rival.

Of recent years, however, the limitations of electricity have become more clearly defined, and in the mean while compressed air has gained a hearing. There are few, perhaps, outside of those who follow the technical journals, who are aware of the immense progress that has of late been made in the employment of this new power, and the astonishing multiplicity of uses to which it is now put.

The Westinghouse air-brake, and the compressed air drill that is to be seen almost any day making excavations for buildings and the like, have long ceased to be regarded as novelties. But it is different when we learn that this same force is now used to start cars, and even to run them, and that this same air drill, working in the mine, has literally added hundreds of millions to the available mineral wealth of the world. The enormous increase in the production of gold, as well as of silver, coal and iron, copper, and other metals, has in no small part been due to this convenient tool. Further, it has been the principal agent in the construction of Chicago's great drainage canal, in many respects one of the most wonderful enterprises of the day.

Then, again, we are all of us aware of the use of compressed air in the Zalinski dynamite gun, which is able to hurl a charge of explosive a mile and a half, sufficient to convert a whole regiment into unrecognizable pulp. It is another matter to learn of this same force cleaning carpets, dusting cushions, and painting cars and barns. And as we go a little further, we find this Protean force operating block signals on our railroads, and steering ships, running clocks, and furnishing cold air for refrigerators, loading guns and handling projectiles on our men-of-war, propelling sewing-machines, doing all sorts of hoisting-work, driving lathes and printing-presses, copying letters, and running summer fans. In Australia it is shearing sheep; in Kansas City beeves are slaughtered and the meat dressed mainly with compressed air. It is an excellent pump, especially for deep wells, and in particular for chemicals. With the same power you may dump a whole train of coal or dirt cars by the pressure of your thumb. It is carving beautiful statuary, and employed in all sorts of stone-work; it makes a good dredge; it raises and lowers railroad gates; it is a valuable agent in the sugar-refinery and in the making of asphalt and rubber, and still again in the delicate manufacture of fine silk. In the coal-mines it is running locomotives, bringing oxygen and life to the exhausted operative, and banishing the fear of deadly explosions. In England a hundred and fifty miles of pneumatic tubing facilitates the rapid transfer of mails, and the same system is in use in Philadelphia, and just recently between New York and Brooklyn. In England, again, employed in the dry docks, compressed air is made to lift huge vessels out of the water as if they were toys, and in the same way it will shortly be introduced on the Erie Canal in working the new quick-action high lift locks. It is a good fire-extinguisher, and an excellent hoist for grain. It is used by the physician and surgeon in many delicate operations. In the railroad shops of Jersey City and many other points it is everywhere running machinery, lifting huge loads, riveting bolts, driving hammers, sand-papering cars. In Paris, under the famous Popp system, where it has had its widest application, it is employed in almost every conceivable variety of work.

Now that this new power has, so to speak, found its feet, it would be difficult to set limits upon the vast variety of uses to which, in the future, it will be put. It forms the basis of the gigantic project of a great ship-canal from the Great Lakes to the sea, described in these pages a year or more ago, which will be equipped with locks capable of raising an ocean liner to the height of Niagara with the same ease as a clumsy canal-barge is now lifted the height of a bean-pole and with much more rapidity. The bicycle tire, the pneumatic cushion and pillow and horse-collar, are but a beginning of its use in this direction, and it seems now the most convenient power for the automobile carriage. And when it is generated in large central stations, and distributed over the city in the same way that gas and water and electricity are now distributed, you may expect, madam, that it will clean house for you—beat your carpets and clean your walls—and take a general hand in your household affairs. It will pick you up and set you down from floor to floor. It will be waiting for you at your door, and whisk you to the shopping districts. It may treadle the sewing-machine, agitate the dish-washer, and smash your costliest china with all the dexterity and *sang-froid* of your most accomplished handmaiden. All this and much more it may do, if we are to believe some of those who are given to peering into the to-morrow of things. These tell us that even now compressed air is an equal-footed rival of electricity, and that while the latter has been thrusting the steam-engine from the field, compressed air has entered the lists against this latest knight of industry.

In view of all these things, its multiplied uses in the present, and the large possibilities of its future, the wonder of it all now seems that compressed air should not have come in long ago. It is not new, any more than electricity is new. In a sketch of its history in an interesting little periodical, *Compressed Air*, published in New York city, the earliest notable use of this power is set down to the construction of the Mount Cenis tunnel. It was first employed on a large scale in this country in the building of the Hoosac tunnel, along about 1866, and from this time its advancement has been steady and sure. But it has been, apparently, the Cinderella of the mechanical arts. It made its appearance in an age given over to a sort of electrical mania, and there seemed no godmother genius like Tesla or Edison to bring the golden slipper to its neglected hearth.

Three notable steps of advance wrought a striking change in this order of affairs. When compressed air was first tried, it was found that the loss of power was enormous. It was difficult to store, for the air leaked rapidly away; it was expensive to generate, and there were thermo-dynamic difficulties in its use without number. When a thousand cubic feet of air is jammed into the space of one, a large amount of heat is developed, and in order to store and use the air this heat must in some way be drawn off. Similarly, air at high pressure, when released, cools rapidly. The result, if there be a sufficient moisture, is freezing and clogging. For a long time it was thought these difficulties were largely insuperable.

Now, however, these very difficulties are turned to a profit—to such excellent profit, indeed, as to afford an apparent paradox. It seems idle to assert that it is possible to get as much power out of a machine as you put into it—this means a frictionless and wasteless mechanism. And yet a very near approach to just this condition seems to have been made in the case of compressed air. This is due to the development of the reheating process. Lest the reader be not familiar with the technique of the subject, it may not be idle to explain its broader features. In the process of compression the air is sucked into a piston, and then rammed into a reservoir surrounded by a water jacket, the latter drawing off the heat generated in the compression. The machine which does this work is a beautiful affair of what is known as the four-stage type. That is to say, the air is first driven up to about eighty pounds pressure and cooled; then turned into a second cylinder, where it is compressed still further, then cooled again; and so on up to the desired point. Thus even at two or three thousand pounds pressure to the square inch the air within the reservoir remains at somewhere near the temperature of the outside atmosphere. But if the air be

used in this condition, not only will a large share of the power employed in compression be lost, but it will, as already noted, have a tendency to freeze everything within reach. If, however, as it is released, it is passed through a heater or is shot through superheated hot water, it will, under the well-known properties of air, enormously expand. In actual practice it has been found possible to add, by reheating, one horse-power to each horse power developed by compression, at one-eighth or one-tenth the original cost of the latter. That is to say, if a given quantity of compressed air costs a dollar to generate, the further expenditure of ten cents in reheating will double its power to do work. Theoretically the total efficiency thus obtained is actually greater than if the same amount of coal had been burned in an ordinary steam-engine and the power thus generated used direct. In practical use it is slightly less.

With the reheating method came a marked improvement in compressing apparatus, in which advance, it is to be noted, the United States has taken the lead. There yet remained a third problem, the same that has baffled the electrician—the question of storage. It was found that air at high pressure is much more penetrating, for example, than steam. Now, however, storage reservoirs have been devised in which the loss from leakage is next to nothing. These are known as Mannesmann tubes, and are simply large, seamless, rolled flasks of mild steel, with but a single vent. These are of high tensile strength, and may be drawn to hold air at very high pressure. With these it is possible to carry a large amount of stored-up energy in a very small space, and without danger, for if these tubes were to burst they would not fly in pieces, but would simply rip, like a leather bag, and beyond a swift rush of air and a loud report there would be no hazard to life. With low cost of generation, economy of expenditure in use, and perfect storage, it remained only to develop the special appliances for its immediate application to give compressed air its present wide range. In particular did this advance make possible its use as a traction agent. The first to experiment in this field were the French. The surface cars to be seen in New York city are by no means the first of their kind. They represent simply an improvement of the well-known Mekarski system of Paris. The latter has been in use in the French capital for something like ten years, and a number of different attempts have been made from time to time to introduce it in this country. The requirements of a service for the narrow and crowded thoroughfares of a city like New York, however, seemed too great for the French system to meet. It was not economical, it was heavy and clumsy, and not feasible in other ways. The Hardie system—that in use in New York city—seems to have overcome these difficulties, and, furthermore, to be able to cope with the peculiar and perplexing conditions which obtain in the congested portions of a large city where the overhead trolley is not allowed.

The cars are identical in appearance, both in side and out, with the type used on the cable or trolley roads, and the motive apparatus is completely hidden from view. It is located entirely beneath the seats and the body of the car, and is controlled by a mechanism that outwardly does not differ from that for the control of the trolley. As the car starts, there is some slight hissing noise, and that is all. The ease with which it is started and stopped does away with the exasperating jerkiness of the cable; and aside from this, the system seems much safer, from the quickness with which the car may be brought to a standstill. In cases of prime necessity the whole force of the compressed air which the car carries may be thrown upon the wheels, and a dead stop from full speed effected in a few feet. The immediate operation would no doubt slightly dislocate the occupants of the car, but it would be a departure from the system of wholesale depopulation and dismemberment which seems the special mission of the trolley. Like the latter, the speed of the motor is variable within wide limits, and much faster runs may be made at night, after the theatre, than is possible with the cable.

The mechanical features of the Hardie motor are exceedingly simple. An apparatus substantially identical with that of the steam-locomotive is supplied with compressed air, instead of steam, from tubes extending under the car seats. These tubes or cylinders are charged at two thousand pounds pressure, but when used the air is passed through a reducing valve, bringing the pressure to one hundred and thirty pounds. The reheating is effected by forcing the air, before its entrance to the valves of the driving-gear, through a chest of superheated water. In its passage through the latter the air is not only enormously expanded, but is converted into a sort of vapor, which, it is claimed, gives a peculiarly high efficiency. In all about fifty-one cubic feet of air is stored in the steel reservoirs, affording sufficient power to run the car fifteen or eighteen miles, including stops. The time occupied in recharging the cars with air and hot water is not more than a minute, so that there is practically no delay. The motor mechanism itself consists of two simple, link-motion, reciprocating engines, which do not differ materially from ordinary steam-engines in their features, save in their use of air. By ingenious device it is possible to start the motor at any point, and there is thus no chance for stoppage over a "dead-centre." It is to be noted that this ability to start promptly under all conditions is a feature the lack of which has been one of the principal causes of failure of air-motors heretofore tried. Still another unique device is that by which a surcharge of air is admitted to the valves in order to accelerate the start, this pressure being shut off when the car gains its full speed. The manipulation of the whole mechanism is exceedingly simple, requiring no more skill than that of the ordinary trolley. The cars move in either direction with equal facility, and are under such perfect control that it is possible to start and stop them within a space of two inches. The same lever that releases the brakes operates the starting-gear, and, similarly, brakes are applied and the air cut off with a single motion of the wrist.

As I am confining myself entirely to the favorable points of the new motor, it may be added that further claim is made for the Hardie motor that it is the cheapest of all systems in point of first cost, since it requires no subterranean or overhead construction, and can be introduced on any track. Each car being independent and carrying its own motive power, no derangement of machinery at the central station or of the "feeder"—that is, of cable or trolley—can affect the whole line. Electrical storms are, of course, no danger, and there are no cables to strand and to afford the reporters for the morning newspapers material for exciting tales of running-away cars. There is no dissipation of energy, as in the case of steam, trolley, or cable, since practically only such power is taken as is actually used. The smoothness of operation represents a further economy, alike of temper and profanity, so that I doubt not the ingenious promoter will hardly fail to represent them as an agency for the moral regeneration of the community.

There remains the single factor of economy of operation. Diligent inquiry upon this point failed to bring forth any really illuminative facts; probably the latter do not exist. It is claimed that compressed air for traction is less than half as expensive as the cable; and there is a further gain in fixed charges, since the cost of insulation is immensely less than in that of the cable of the underground trolley. This can only be demonstrated by actual experiment, such as is now being made in New York. Aside from the trial on the 125th Street line, the same company has now under construction a compressed-air locomotive which will be employed to draw a train of five cars on the Manhattan Elevated Railroad between Rector and 58th Streets. Still further, besides the Hardie system, the Metropolitan Railroad has on trial yet another compressed-air motor, the invention of W. J. Knight and Joseph H. Hoadley. Three cars of the latter construction are now in use on the Lenox Avenue line, but of their capability, as of their special points of construction, the inventors do not as yet care to speak.

The detail of the development of compressed air here given is necessarily but a sketch, but even this will disclose that much more than a beginning has been made. The general use of the new power will come only with the advent of large central distributing stations, from which it can be had as freely as is gas or water now. While in a sense it is a rival of electricity, yet it is not impossible that it will soon become a yokemate rather. The alternating electrical current may be employed to transmit cheap power long distances, as from Niagara and the Pennsylvania culm-banks, and this power converted into compressed air at the point of consumption—electricity being probably the best agent for distance transmission, and compressed air the most mobile form of power for immediate use. Even this is mere conjecture, however, since there is at least one engineering genius—a man of remarkable achievement at that—who has distinctly in view the compression of air at great water-powers like Niagara, conveyance by pipe-lines, at enormous pressure, so far as New York or Philadelphia, and delivery at prices with which electricity cannot compete. But whether as yokemates or rivals, it must be clear to the dullest imagination that present conditions are but a stage, and that we are but on a threshold of the day when these two forces, harnessed and trained, will, from their cheapness and availability, and in their infinite application, lift a considerable share of the burden of physical toil from the shoulders of the race.

CARL SNYDER.

COMPRESSED AIR FOR CITY AND SUBURBAN TRACTION.*

By Herman Haupt.

Although a considerable amount of compressed air literature has been given to the public during the last two years, there is still a want of information as to the efficiency and economy of air motors as compared with cable, electric and other systems, and statements are continually published in the columns of the daily press that exhibit ignorance of scientific facts and apprehension of imaginary dangers.

Compressed air motors have been in successful operation in France for many years, and they are now rapidly establishing themselves in public favor in the United States. They have been constructed and tested at Rome, New York, continuously for two years, in all conditions of weather, and have given satisfaction even at temperatures below zero. Several motors are now, and have been, running for some months on the One-hundred-and-twenty-fifth Street Railway, in the city of New York, in daily service, without having lost a trip and with great satisfaction to the public.

The attention of the writer was first directed to the use of compressed air for city service in 1879, when he was called upon to examine, test and report upon several motors that had been constructed under the supervision of Robert Hardie, and allowed to be run on a portion of the Second Avenue Surface Railway, at Harlem, in New York. These motors were tested for several weeks, and the results were entirely satisfactory; but all attempts to secure their introduction proved fruitless. There was so strong a prejudice against them, that the president of one of the city railroads in Philadelphia declared that he would not have such a motor on his road if it saved the whole cost of horse-power; that it would frighten every team on the street to see a car running without horses, and the company would be perpetually annoyed by lawsuits. Explanations proved useless, and efforts were abandoned.

After the far more objectionable and expensive cable and trolley systems had been introduced and had demonstrated that a car could be run without horses and without frightening teams, the writer renewed efforts to educate the public, and especially the profession, in regard to the superior merits of compressed air. A book was published, giving a description and comparative cost of all the systems known or used for city traction, based on similar conditions of service.

This was followed by a number of monographs on special points, and finally resulted in the formation of a syndicate to raise capital and organize a company under the title of the General Compressed Air Company. The services of Mr. Robert Hardie were secured as engineer, and a motor constructed at the Rome Locomotive Works, which proved entirely successful from the start, and has been examined, tested and favorably reported upon by engineers, experts and scientists from all parts of the United States without exception.

Very erroneous opinions have been and are yet entertained in regard to the power lost in compressing air, the frost produced in expansion, the danger of explosion, the reheating of dry and moist air, the cost of plant, the necessity for frequent renewals of air supply, the possible length of run, the loss by transmission of air to distant points, and other matters connected with the practical application of air as a motor-power.

That the subject of air motors may be intelligibly presented, it is necessary to state briefly some of the properties of air and the laws which govern its compression, expansion and distribution, also such of the properties of steam as enter into the consideration of the questions at issue.

PHYSICAL PROPERTIES OF AIR AND STEAM.

Air at a temperature of 32° F. requires 12·433 cubic feet to weigh 1 pound; at ordinary temperature about 13 feet.

* Read by title, November 18, 1896.

The weight of steam at 212° is 26·4 cubic feet to the pound, or approximately, for rough calculation, 26 feet. *Specific heat*, or capacity for heat, varies with different substances, and it is a very important element in calculations in thermodynamics. Water, having the greatest capacity for heat, that is, having a capacity to retain the greatest number of heat units per pound, has been taken as the unit of specific heat. On this standard, the specific heat of air is ·2377, or approximately ·24.

The specific heat of steam is ·475, or approximately ·48, or double the specific heat of air. In other words, steam is half as heavy as air, but has double the capacity per pound for retaining heat.

If air be suddenly compressed to one-half its volume, the temperature will be raised 116°, and if suddenly expanded to double its volume the temperature will be reduced to the same extent.

Under high pressure a given increase of pressure will develop much less heat than at low pressure. For example, a given volume of air at atmospheric pressure, condensed suddenly to one-half by an increase of pressure of 15 pounds, would develop 116° of heat, while under a pressure of 25 atmospheres an increase of pressure of 1 atmosphere would raise the temperature only 16·7°.

A thermal unit, or unit of heat, is the quantity of heat that will raise the temperature of 1 pound of water 1°, and a thermal unit is the equivalent in work of 772 pounds raised 1 foot.

A horse-power is 33,000 pounds raised 1 foot in 1 minute.

Isothermal compression is compression without evolution of heat. If this were attainable in practice, as much energy could be utilized in the expansion of air as was expended in compression.

Adiabatic compression is compression with evolution of heat. By compression and intermediate cooling it is claimed that 80 per cent. efficiency may be obtained. Under old systems of compression the loss has been conceded to be 50 per cent. The capacity of air for holding moisture is affected by volume and temperature, but not by density. A cubic foot of air will hold no more water at the same temperature under 133 atmospheres than under 1; consequently, when this air is expanded to original tension, 1 cubic foot will contain only $\frac{1}{133}$ part of the moisture that it had originally and should be too dry to form a deposit of ice at the exhaust even if not reheated. Only low pressures can contain sufficient vapor to cause trouble; but as air should always be reheated, for reasons that will be explained, the difficulty from frost is purely imaginary.

Absolute or theoretical zero is a point determined by theory 461° below the zero of Fahrenheit, from which temperature must be estimated in problems connected with expansion of elastic fluids, the volumes being in proportion to the temperatures from absolute zero. This datum will be found essential in considering the question of reheating.

Latent heat is the heat that disappears or becomes latent in change of form, as from a solid to a fluid, or from a fluid to a vapor, and which reappears by condensation when the original condition is resumed.

In the liquefaction of ice 142·5 units of heat per pound become latent, and in the conversion of water into steam 966 units; so that the latent heat of water from ice is 142·5 units, and of steam 966°.

The specific heat of ice is ·50, so that the number of thermal units in 1 pound of steam at 212°, measured from absolute zero, will be $(461 + 32) \times ·50 + 142·5 + 180 + 966 = 1{,}535$ units.

An apology for these explanations and definitions seems to be required, as they apparently assume a want of information on the part of the reader, but there seems to be a necessity for explanations to remove the ignorance and prejudice that are almost universal. Even in technical journals, articles have appeared from the pens of gentlemen of high scientific reputation advocating the reheating of *dry* air to increase its power, and giving plans of apparatus for the accomplishment of this object. It will be shown that to double the power of dry air by an application of heat is practically impossible, and that it is only by an admixture of vapor that satisfactory results can be secured, yet this

demonstration could not be given without furnishing the data which it required.

AIR COMPRESSORS.

The use of compressed air for the operation of rock drills and for other purposes has become so extensive that it has led to great improvements in compressors, and several companies are now engaged in their manufacture who will furnish plants at moderate prices and guarantee results. Among these can be named the South Norwalk Iron Works Company, the Ingersoll Sargeant Drill Company and the Rand Drill Company. The best results are secured by repeated compressions with intermediate cooling, and large plants should always consist of a number of units, so that repairs to one will not affect the remainder, and the number in use at one time can be regulated by the demands of the traffic.

The experience gained by numerous tests, extending over a period of years, has furnished positive and reliable data by which to determine the amount of free air, under compression, required for any given service under any ordinary conditions. If responsible manufacturers of compressors will agree to furnish the plant at a given price, with a guarantee to compress a given number of cubic feet of free air per minute, delivered in station reservoirs under a given pressure, with a coal consumption and horse-power within prescribed limits, all elements of uncertainty as to cost of power seem to be removed; and this is being done.

The improvements in compressors have greatly increased their efficiency and extended the use of compressed air. In the primitive types an efficiency of 50 per cent. only could be secured; now 80 per cent. is claimed, while the ability to transmit power by this agency to long distances without serious loss, and to concentrate many small powers into a general reservoir will permit many water-powers to be utilized that would otherwise be worthless, and secure economies not offered by any other system.

The sudden compression of air is attended with a great evolution of heat. To compress two volumes of air into one, as previously stated, will raise the temperature 116°; but it is a remarkable and valuable property of air and other elastic fluid, that under high pressures a given increase requires less power and develops less heat than under low pressures.

If, for example, it should be required to compress 3,600 cubic feet of free air per minute to a pressure of 500 pounds, the horse-power required would be 1,060 horse-power; if to 1,000 pounds the power would be 1,219 horse-power—a difference of 159 horse-power for 500 pounds; if to 1,500 pounds pressure, 1,288 horse-power, or a difference of 69 horse-power for 500 pounds; and if to 2,000 pounds, 1,339 horse-power, or a difference of only 51 horse-power to gain 500 pounds of additional pressure.

The power required to compress 1 cubic foot of free air is estimated as follows:

	Horse-power.
To 500 pounds pressure per minute	0·316
To 1,000 " " "	0·364
To 1,500 " " "	0·385
To 2,000 " " "	0·400

To which 10 per cent. allowance should be made in practice in allowing actual power for compressors.

Mr. E. Hill, the General Manager of the Norwalk Iron Works, gives absolute isothermal compression to 2,000 pounds per square inch per cubic foot of free air per minute, 0·315 horse-power, and the best possible in practice under the most favorable conditions, 0·378 horse-power. The computation of the writer gave 0·348 horse-power as the theoretical isothermal, but 0·45 should be allowed in practice. It is better to provide an excess of power than to suffer the inconvenience of a deficiency.

RE-HEATING.

A remarkable property of compressed air is that its efficiency can be doubled by re-heating. This is not theory; the fact has been confirmed by actual demonstration, both in Europe and America. It may appear incredible and contrary to well-known physical laws that the efficiency

of air can be doubled by simply passing it through a tank of hot water before admission to the motor cylinders, but such is the fact, and the reheating which doubles the power represents a consumption of coal only one-eighth of the amount required at the power station to produce the compression.

A direct test was made at Rome, on motor No. 100, in the presence of Capt. G. J. Fiebeger, of the U. S. Engineers, now Professor of Civil Engineering at West Point. The consumption of re-heated air from an average of many runs was 308 cubic feet per mile. When the re-heater was emptied of water, the volume of cold air required was 669 cubic feet per mile.

An explanation of this remarkable result will be given.

A comparison will be made between the results of re-heating dry air to an extent sufficient to double its volume with and without the assistance of water, assuming the volume at 60° to be 300 cubic feet of free air, and that it is to be admitted to the motor cylinders under a pressure of 150 pounds to the square inch.

Assume, in the first place, that air at 60° is passed through a tank of water at 360°, giving a steam and air pressure of 150 pounds per square inch. The units of heat required to double the volume will now be determined.

The absolute temperature at 60° is $60 + 461 = 521°$.

The absolute temperature at 360° is $360 + 461 = 821°$, so that the air passing through water at 360° will be increased in volume, or under constant volume will be increased in pressure 63 per cent.

The thermal units required for the increase of temperature will be, 23 pounds of air raised 300°, specific heat of air being .24. Then $23 \times 300 \times .24 = 1{,}656$ units. The air has been increased in pressure 63 per cent., and to double the pressure by the addition of vapor or steam from the water will require the addition of 111 cubic feet of steam at atmospheric tension. That is, the 300 cubic feet of air at atmospheric tension has been increased to 489, and $489 + 111 = 600$. The 111 cubic feet of steam weighs 4.3 pounds, to secure which from water at 360° requires only the latent heat, or 863 units. $863 \times 4.3 = 3{,}711$, and adding the 1,656 units previously obtained, will give a total of 5,367 units.

Coal completely consumed will furnish 13,000 units per pound, petroleum 20,000 units per pound, and allowing for loss by imperfect combustion, 1 pound of coal or ½ pound of petroleum should furnish the fuel for re-heating at a cost of 2 mills for coal or 1¼ mills for crude petroleum, and 300 cubic feet of air thus re-heated should run an 8-ton motor much more than 1 mile.

To double the volume of air by the application of dry heat, the temperature must be double from absolute zero. At 60° observed temperature the absolute temperature would be $60 + 461 = 521°$, and the double would be 1,042°, and deducting 461° would leave the equivalent thermometric temperature 581°, a degree of heat that would burn out the lubricants and would be entirely inadmissible. In fact, it is stated in a recent work on compressed air by Mr. Frank Richards, that to double the power with dry air would require a temperature of about 800°, in consequence of the low specific heat of air and consequent rapid cooling.

As the air is supposed to be used expansively, so that the atmospheric tension is reached at the end of the piston stroke, the quantity of heat lost by expansion with an initial pressure of 10 atmospheres, or 150 pounds, would be 494°, which is nearly all that the heated air contained, so that if the admission could be at 581°, the exhaust would be 87°, without allowance for loss by radiation or conduction, and so much heat would be absorbed by the cylinder that the efficiency of the re-heated air would be greatly impaired.

On the other hand, if the air be passed through hot water, any vapor condensed in the cylinder yields its latent heat and steam, also acts as a lubricant.

Another striking comparison will be presented. Steam at 350° temperature and 150 pounds pressure, will, in cooling down to 212°, impart more than thirty times as much heat to the cylinders as an equal weight of air between the same temperatures.

The difference of temperature is 350 — 212 = 138°.
Specific heat of steam, ·475; air, ·24.

	Units.
1 pound of steam yields 138 × ·475	65·5
and of latent heat	966·0
Total heat from 1 pound of steam	1,031·5
1 pound of air reduced 138° yields 138 × ·24	33·12

One pound of steam carries as much heat as 31 pounds of air, and not only serves with little loss to maintain the cylinder and passages at a proper temperature, but, as previously stated, it also serves as a lubricant.

The reasonable conclusion is that it is practically impossible to heat dry air to an extent sufficient to double its power, and if practicable it would be inexpedient and the effect highly injurious.

The ideal re-heater would be a tank containing water at a temperature to furnish steam at the pressure of the air as used in the motor cylinders. The heat retained constant and uniform by cheap fuel, such as crude petroleum, and in winter the cars to be heated by water circulation from the same tank.

From tests made by him in 1879, the writer concluded that the average amount of water absorbed by the air and carried over in the form of steam was about 1 pound for 50 cubic feet of air. The accuracy of this result having been questioned, Mr. Hardie was requested to make a series of tests at Rome, the result of which established the fact that the quantity of water absorbed and carried over was dependent upon the temperature. At a high temperature in the water a comparatively small volume of air would suffice to evaporate a pound, and at a low temperature the volume of air was greatly increased.

The following table is interesting, showing the number of cubic feet of air at atmospheric tension required to absorb and carry over 1 pound of water in the form of steam or vapor:

Degrees F.	*Cubic Feet.*
At 321	35·2
At 300	42·5
At 296	43·3
At 274	48·5
At 259	95·2
At 210	159·0
At 190	238·0
At 182	229·0
At 170	221·0
At 164	459·0
At 158	493·0

RESERVOIRS.

The subject of reservoirs is one of the most important in connection with the construction of compressed air motors. The reservoir is the source of power in the motor, and upon its capacity and strength the possible length of run depends. Formerly, reservoirs were constructed of riveted boiler plates, and were capable of sustaining a pressure of from 300 to 600 pounds per square inch only. Consequently, a run of over 10 miles required so great an extension of capacity that room could be secured only by raising the floor to an inconvenient height above the rails. To secure long runs, with moderate reservoir capacity, high pressure is a necessity, and reservoirs are now manufactured, by a peculiar process, from solid ingots of mild steel, without a joint or weld, and which are capable of sustaining with safety a pressure of 2,000 pounds per square inch, the test, within the limits of elasticity, being carried to 4,000 pounds, leaving so large a factor of safety as to render rupture impossible.

It is proper to observe that the risk of rupture is not greater under a pressure of 2,000 pounds than it would be under 500 pounds, for the thickness of the shell would be four times as great with the higher pressure, and the strain per square inch of metal would be precisely the same in both cases.

Paradoxical as it may seem, it can be shown that a pressure of 2,000 pounds per square inch is actually more safe than a pressure of 500 pounds, notwithstanding the fact that newspaper scribblers, in the interest, apparently, of

rival systems, to create a prejudice against compressed air, magnify the risks of an explosion and the dangers to result therefrom.

Bear in mind that all reservoirs intended to carry 2,000 pounds are tested to 4,000 pounds, within elastic limits; consequently, the pressure could be increased 2,000 pounds more before the danger limit could be reached.

But if the pressure were 500 pounds the margin of safety would be the same, and the test would be to 1,000 pounds. Consequently, a variation of 500 pounds increase of pressure would reach the danger limit with the low-pressure reservoir, but would be 1,500 pounds below this limit with the high pressure. There can be no question of the sufficiency of the margin of safety.

But if, notwithstanding the theorizing upon the subject, the reservoirs should actually burst, would not the consequences be disastrous? The answer is no! A rent would be formed and the air would escape with a hissing noise. The material, unlike cast iron, is ductile and will stretch and pull apart and not fly in pieces.

The following extract from a letter from the manufacturers in Germany, addressed to the writer, will afford an explanation:

"Regarding the reservoirs, we put them to a test yesterday to state the elastic limit. It was reached at 3,500 pounds, but we went further in our experiments in order to demonstrate by practical test (as it has been demonstrated in hundreds of bursting tests of carbonic acid bottles) that these air bottles would not crack or fly to pieces, but that they would simply open when the breaking strain was reached (as was always the case with the carbonic acid bottles, when tested to bursting strain) and allow the contents to flow out, proving thereby that the handling of these bottles is in no way dangerous. We, therefore, think it advisable and safer for the future practical use of the bottles, not to test them, as we mutually agreed, till near to the bursting strain, but only till near to the elastic limits, because we are afraid that although they stand the test till near the bursting strain, the metal is somewhat weakened and, therefore, the practical use afterwards diminished. You will find the bottles somewhat lighter than ordered, and the question to decide for future deliveries will be whether you want the bottles as light as possible and use a storage pressure of 1,500 pounds per square inch, or if you prefer to make them somewhat heavier and use a storage pressure of 2,000 pounds per square inch. Please answer if you agree to the above, and we will send you the whole lot immediately. To-day we send you eight bottles, seven medium long and one short one, that you may, if you choose to do so, repeat the test to 3,500 pounds. As the fluctuations of the compressed air pressure, caused by the fluctuations in the atmospheric temperature are small when compared with the same fluctuations of the carbonic acid, we think it safe to test the air bottles only to the elastic limit, and use them with about half that pressure in practical work, as this way is safer than to test the bottles to the bursting strain and charge them only with one-third of that pressure afterwards in practical use."

Similar results have been indicated by tests in other localities, and it must be remembered that the rupture of a cylinder containing air produces effects that are widely different from those which result from the explosion of a steam boiler. When a boiler explodes, the volume of steam may be instantly increased more than a thousandfold by the conversion of water into steam by the reduction of pressure, the boiler is ruptured and pieces of iron and scalding water projected to great distances, while the rupture of an air cylinder allows a comparative moderate expansion of the contents, accompanied by a sensation of cold and not of heat.*

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* To illustrate more clearly the effect of the explosion of a steam boiler, let it be assumed that the dimensions of the boiler are 3 feet diameter and 12 feet long, containing 85 cubic feet, of which 70 cubic feet are water and 15 cubic feet of steam at a temperature of 350°.

The 70 cubic feet of water will weigh 4,375 pounds, and at 350° will contain 1,531,250 units of heat.

The 15 cubic feet of steam at 15 atmospheres will weigh 9 pounds and contain 10,602 units, and the whole contents of the boiler 1,541,870 units of heat.

Let x = quantity of water at 212° not converted into steam by the explo-

WEIGHT OF RESERVOIRS.

The weight of reservoirs is in proportion to the number of cubic feet of free air that they inclose, and that again is in proportion to the length of run, and is entirely independent both of diameter and pressure.

The truth of this position can be demonstrated rigidly, but a simple explanation will suffice to make it clear.

Suppose a reservoir of any diameter, say 1 foot, is under a pressure of 2,000 pounds per square inch, 1 foot in length of such reservoir will weigh a certain number of pounds.

Now, suppose the diameter should be reduced to one-half or 6 inches, the thickness of metal to resist the pressure would be one-half as great as formerly, and the circumference also one-half, consequently the weight per foot would be one-fourth; but to secure equal capacity the cylinder must be four times as long, and, therefore, the weight, with a given capacity, must be the same whatever the diameter.

Again, suppose the pressure should be reduced from 2,000 to 1,000 pounds per square inch, the weight to resist this pressure would be reduced one-half, but to contain the same quantity of free air the capacity must be doubled, and, consequently, the weight would be the same as before.

It follows, therefore, that whatever may be the diameter of the reservoir or the pressure per square inch, the weight of reservoir to enclose a given *weight* of air will be constant.

What then is the weight per cubic foot of interior capacity required to resist a pressure of 2,000 pounds per square inch, equivalent to 136 cubic feet of free air?

If 35,000 pounds be assumed as the elastic limit of the material, and one-half, or 17,500 pounds, as the maximum strain upon the metal per square inch from an interior pressure of 2,000 pounds, then it will be found that the weight per cubic foot of interior capacity will be 115 pounds. The weight of the last importation of the German reservoirs was 106 pounds per cubic foot of interior capacity.

As the 115 pounds per cubic foot under 2,000 pounds pressure contain 136 cubic feet of free air compressed into 1 foot, the required weight of reservoir will be 0·856 pound for each cubic foot of free air that may be enclosed.

If, in addition, it should be assumed that 400 cubic feet of free air should be provided to run an 8-ton motor 1 mile, with sufficient allowance for contingencies, the weight of reservoir per mile run would be 338 pounds. This weight, it must be understood, applies to the motor only, and is the equivalent of 42 pounds per ton of motor weight. Trail cars will require only about one-third as much per ton.

[*To be concluded.*]

sion. Then $4,375 - x$ = water converted into steam at 212°. Latent heat, 966 units. Then $212 + (4,375 - x)\ 966 + 10,602 = 1,541,870$. From which $x = 3,600$ pounds, and $4,375 - 3,600 = 775$ pounds of water converted into steam by the explosion = 20,176 cubic feet, $20,176 + 225 = 20,401$ = cubic feet of steam liberated, and $20,401 \div 15 = 1,360$ times the original volume of steam which has been increased by the explosion.

COMPRESSED AIR FOR CITY AND SUBURBAN TRACTION.*

By HERMAN HAUPT.

[*Concluded from p. 26.*]

RESULTS OF TESTS.

Compressed air motors have long since passed the experimental stage. They have been running for two years at Rome, N. Y., and through the kindness of the officials of the New York Central Railroad have been repeatedly allowed to run on the main track, where a speed has been attained of 30 miles per hour with wheels of only 26 inches diameter.

It should be obvious to every person of intelligence that

* Read by title, November 18, 1896.

a compressed air motor can be planned to fulfil any conditions, or perform any service, within the capacity of a steam locomotive. Speed requires large wheels, length of run large storage. High grades and heavy trains require large cylinders. The motor must be adapted to its work and fulfil the conditions of its service.

Tests have been made repeatedly by engineers and experts from all parts of the country, all of whom, without exception, have made favorable reports. One of these tests, made in the presence of the writer and of Captain Fiebeger, of the U. S. Engineers, February 18, 1895, gave the following results:

Starting with a pressure of 1,900 pounds in motor, and temperature of 291° in the water of the reheating tank, the first six runs of 4,800 feet were made on an average of 221½ cubic feet of free air per mile.

The next six runs of 4,800 feet, temperature 252°, required an average of 339 cubic feet per mile.

The water in the tank was then reheated, by attaching a steam hose, to 302°, when the next run was made on an average of 208½ cubic feet per mile, from which the required quantity of air increased as the water became colder to 377 cubic feet per mile. After the tenth run, the water was again reheated, and the quantity of air fell per mile to 247 cubic feet, and then increased to the fifteenth and last run, when the temperature was 247° and the quantity of air per mile 521 cubic feet.

The average expenditure of air during the whole test was 308 cubic feet per mile. When the water was emptied from the tank and cold air used, the consumption was 661 cubic feet per mile on the same track.

This motor was calculated to run a maximum distance of 12 miles, with one charge of air, but as the reservoir capacity was 35 cubic feet, under 136 atmospheres, the cubic contents of free air was 5,760 cubic feet, which, divided by 308, gives 18·7 miles as the possible run if all the air could have been used. Allowing 2·7 miles as a reserve, there would still have remained an effective run of 16 miles. There can be but little doubt that by an efficient system of reheating, whereby the temperature could be maintained at 300°, a greater efficiency could be secured.

It is unnecessary to give the results of other tests; they have been quite numerous, and by different experts, and confirm substantially the conclusion above stated.

The motors now running daily on the One-hundred-and-twenty-fifth Street railway in New York make 17 miles with one charge of air. The reservoir capacity, 50 cubic feet.

Why is compressed air cheaper, both in installation and in operation, than any other system of traction for city and suburban service?

It requires less power at the power station for a given service, and this means less cost for engine plant and a perpetual saving in coal consumption.

A comparison with the trolley must be based on similar conditions, and as the recognized maximum distance of transmission of electrical power under 500 volts is 5 miles, a line of 5 miles, double track, with two-minute headway, will be assumed as a basis of comparison, average speed 10 miles per hour, and 30 motors on line.

Electrical motors are usually supplied with two 25 horse-power motors, making 50 horse-power each, but as the full power is required only in overcoming the maximum resistances, the power provided at the power station is usually calculated upon a basis of transmission of 25 horse-power for each motor.

This transmission involves many losses, and only a comparatively small portion can be actually utilized at the rail.

In the *Engineering News* of October 17, 1895, p. 256, is found the following estimate, the indicated power of the engine at the power-house being taken at 100:

	Per Cent.		*Per Cent.*
Engine friction	8	Remains	92·0
Belting and shaft	10	"	82·5
Dynamos	8	"	76·2
Transformers at power station	7	"	70·9
Line to sub-station	12	"	62·4
Transformers at sub-station	7	"	51·8
Rotary converter	16	"	48·8
Railway circuit	10	"	43·8
Car motor	15	"	37·2

This estimate gives only 37·2 per cent. of the indicated power at the station as effective at the rail; but as other estimates claim a higher efficiency, it will be assumed as 50 per cent.

The thirty motors on the track will therefore require 1,500 horse-power as the prime mover at power-house.

Thirty air motors, with a run of 10 miles, will require 4,000 cubic feet of free air, or 2,000 cubic feet per minute, compressed to 2,000 pounds, and the horse-power at the station will be 900, or 600 less than with electricity, and there is no loss in transmission.

COMPARATIVE COST OF MOTORS.

It is usually claimed that the cost of compressed air motors is considerably greater than the cost of electrical motors for equal service.

This is a mistake; the comparison must be made under like conditions. The compressed air motor carries its power with it. The electric motor takes it from the line. A fair and just comparison requires that the cost of plant to furnish power on the line should be included or omitted in both cases.

Omitting the reservoirs, estimates for the air motors have been brought below the electric motors, notwithstanding the low price of the latter, due to active competition; but allowing the cost to be the same in both systems, a comparison will be made between the reservoirs for thirty motors and the line construction required to furnish the electrical power for an equal number.

The thirty air motors will require 110,000 pounds of reservoir, costing about $15,000; per motor, $500.

The cost of line work for 5 miles of double track, with thirty motors, will be $26,000; per motor, $866.

POWER PLANT.

Another great saving is effected in the cost of power plant. It is usual in electrical estimates to allow $80 per horse-power at the power station, exclusive of land and buildings for engines, boilers, shafting, belts, dynamos and other apparatus.

The cost of 1,500 horse-power, at $80 per horse-power, would be $120,000.

Compressed air requires no dynamos, belting or shafting. Steam from simple boilers is piped directly to the compressor, and it would be an excessive estimate to assume that the cost is one-half that of electricity, or $60,000.

SAVING IN TRACK.

The track for air motors requires no girder rails or electric binding or welding. A simple cross-tie track, as is used for ordinary locomotives, is sufficient. The reason for this is that the weight on the air motor is spring-supported, and on the electric motor a much heavier load is rigidly attached to the axle. From a table furnished to the writer by Franklin L. Pope, it appears that the effect of a blow of 1 ton from a wheel passing over an obstruction $\frac{1}{8}$ inch in height, at a speed of 20 miles per hour, is twenty-seven times as great when the weight is rigidly attached as when it is relieved by springs.

The saving with compressed air increases with the magnitude of the plant. Without encumbering this paper with detailed estimates, it is proper to state that the writer prepared a close estimate of the relative cost of electricity and compressed air for a transmission of 5 miles from the power station on an elevated railroad, such as the Third Avenue Railroad, in New York, with trains running at one-minute intervals. The estimate for electricity was submitted to a prominent electrical engineer and pronounced correct. The cost was more than double that of the compressed air installation. In fact, the return electrical current could not be transmitted in the ordinary way by rail, but would require some special arrangement. The attempt to reduce the cost of copper by increasing the voltage of transmission is attended with great increase of risk to life.

A system that may prove satisfactory on a small scale and with a limited volume of business may result in failure

if extended beyond certain limits. President Vreeland, of the Metropolitan system, in New York, in an interview recently published in the *Herald*, pronounced the underground electric system in Lenox Avenue unsuited for a line with a heavy business. It required sometimes from two to four days to locate a defect, which, when found, could be remedied in ten minutes.

In selecting any system for adoption, the sensible course is always to get estimates in detail from competent and unbiassed engineers, covering every point of installation and of operation, and then find responsible contractors to guarantee the work within the limits of the estimates.

COST OF OPERATION.

It has been shown that the cost of installation of a compressed air system is much less than that of the ordinary cheap trolley with wooden poles. If it can be shown also that the operation is more economical, then there can be no question as to its superiority in this particular over the cable, underground electric and other systems, all of which are much more expensive than the trolley.

The following is the latest revised estimate of an engineer long connected with electric companies and familiar with all details of operation, but at present engaged in the introduction of compressed air installations:

MOTIVE POWER PER CAR MILE (run 120 miles per day).

	Cents.
Anthracite coal for compressor plant	0·870
Anthracite coal for reheating	0·110
Water, boiler-feed, etc.	0·022
Oil, waste, etc.	0·024
Removal of ashes, etc.	0·014
Operating labor	0·615
Maintenance of power plant, etc.	0·163
Maintenance of motors, etc.	0·280
Interest and general expenses	1·760
	3·858

TRANSPORTATION.

	Cents.
Maintenance of cars, trucks, buildings	1·619
Motormen, conductors, etc.	6·133
General expenses, interest, etc.	1·:55
	12·765
Electricity, similar items included, costs	16·268
Difference, 27 per cent.	3·503

SOME INTERESTING FACTS.

By reheating the air required for the operation of a motor, the efficiency may be so much increased that more power may be utilized in the motor cylinders than was expended at the power station in the compression of the air.

This statement has often elicited a smile of incredulity as it seems to be in violation of the law of the conservation of energy, but it is susceptible of a simple explanation.

Take the horse-power at the compressor, say 1,400 horse-power to compress 3,600 cubic feet of free air per minute to 2,000 pounds, the foot-pounds in ~~10~~ 7 hours would amount to 5,544,000,000.

The number of motors that this amount of air would supply is 120, assuming cylinders 6 x 14 inches; wheels, 26 inches in diameter; speed, 6 miles per hour; consumption of free air, 300 cubic feet per mile; pressure, 140 pounds per square inch, cut off at one-tenth stroke; mean pressure, 46·2 pounds per square inch. These conditions would give 6,802,272,000 foot-pounds of work in the cylinder of the motors, or 22 per cent. more than the foot-pounds of power expended at the compressor.

How can this be explained? Simply by the reheating of the air, which increases its volume and by the steam which accompanies it and adds greatly to the effect.

But if air is reheated and steam used as an auxiliary to increase the effect, will not the expense of reheating fully offset any advantages thereby secured?

COST OF REHEATING.

From tests made in 1879, it was found that for 50 cubic feet of free air passed through the reheater, 1 pound of water, in the form of steam, was absorbed; 300 cubic feet of air would, therefore, absorb 6 pounds of water. Under a pressure of 140 pounds, the temperature would be 353°, or for effective pressure of 140 pounds, the absolute pressure

would be 160 pounds and temperature 364°. The latent heat at this temperature is 858°.

The heat units required to raise 6 pounds water from 60° to 364°, including the latent heat, will be 1,162 × 6 = 6,972 units. To raise the temperature of 300 cubic feet of air 23 pounds, from 60° to 364°, specific heat of air being 0·24, will be 304 × 23 × 0·24 = 1·678 units.

The total units required for reheating for 1 mile will, therefore, be 6,972 + 1,678 = 8,650 units, which would be supplied by four-fifths of 1 pound of coal, at a cost of $1\frac{1}{5}$ mills.

This coincides very nearly with Mr. Hardie's experience, that the cost of reheating was about one-eighth the cost of compression.

EXPANSION IN REHEATING.

Fifty cubic feet of dry air carries over 1 pound water, which in steam, at atmospheric tension, gives 52 per cent.

Air at 60° F., heated to 364°, will expand in proportion of 461 + 60 to 461 + 364, or 521 to 825, which is 58 per cent. Total increase of volume, 110 per cent. Hence, 300 cubic feet will become 633 cubic feet. Without reheating the water on the trip, the Hardie motor, at Rome, consumed 331 cubic feet per mile, 110 per cent. of which would be 695 cubic feet. The actual consumption of dry air was 661 cubic feet.

INFLUENCE OF SPEED IN CONSUMPTION OF AIR.

A very general, but very erroneous, impression appears to exist in regard to the increased consumption of air in traction motors, due to an increase of speed.

It is assumed that the consumption of air must be in proportion to the horse-power, and as the space passed over in a given time must be doubled, the horse-power, in which space is a factor, must be doubled, and the consumption of air doubled also.

This is true, but the consumption of air *per mile* is not doubled by doubling the speed. The consumption of air is in proportion to the resistances to be overcome, and within reasonable and ordinary limits these resistances are but slightly increased by increase of speed. It is an error, also, to suppose, as many do, that in trolley motors an electrical attraction between the wheel and rail increases adhesion.

In support of these positions, authorities will be quoted. Oscar T. Crosby, in *Transactions* of American Institute of Electrical Engineers for August and September, 1894, states: "The adhesive coefficiency between the wheel and the rail is not increased in any practical degree by the passage of the current. In other words, there is no electrical attraction, as some suppose, between the wheel and the rail to increase adhesion. The adhesion is due to the weight on drivers alone."

The train resistances at high speeds do not increase, as is usually supposed, as the square of the velocity. At 86 miles per hour the total resistance per ton was only 13·4 pounds; 347 tons were carried at 86 miles per hour on a line by an expenditure of 1,068 horse-power.

The resistance of the air is a function of the first instead of the second power of the velocity.

From 40 to 80 miles per hour, the tonnage coefficient is practically 8 pounds per ton on first-class roads and best rolling stock.

Wellington, in his popular work on engineering, pages 922–924, makes statements as follows:

"Journal friction is variable, and is usually taken at 8 pounds per ton.

"The load per square inch on journal bearing has very little influence upon the friction.

"The velocity of the lowest journal friction is from 10 to 15 miles per hour.

"With good lubrication there is very little increase of journal friction up to 55 miles per hour.

"The coefficiency of journal friction is approximately constant at velocities from 15 to 50 miles per hour.

"The power required to overcome inertia and accelerate trains is about three times as much as to maintain velocity.

"The additional power required to get up speed is 45 pounds per ton to give 15 miles per hour in 3,340 feet.

"The air resistance at 10 miles per hour is less than $\frac{1}{3}$ pound per square foot.

"The principal resistance, except axle resistance, is due to oscillation and concussion, which, at 10 miles per hour, may be taken at $\frac{1}{2}$ pound per ton."

The above quotations from standard authorities do not sustain the statement of the expert of the General Electric Company, who stated in a criticism upon an estimate of the writer, that "a calculation, which it is not necessary to enter into, will show that to make an approximation to the average speed of 20 miles per hour, 600 horse-power will be found *not* sufficient to do the work. Where the speed of an electric train is reduced to that assumed for the steam train (10 miles per hour) 300 horse-power will be found abundantly sufficient."

The inference would appear to be, that if the speed of an electric train is increased from 10 to 20 miles per hour, the power must be increased from 300 to 600 horse-power. If this be true, it is very bad for electricity, for it is not true in regard to either steam or compressed air. The power required must always be sufficient to overcome resistance, and if, as appears from the authorities quoted, the resistances are but slightly increased by increase of velocity, there cannot be any great increase of power required per mile of distance traversed as measured by consumption of air or steam. There must be some, of course, but in ordinary service it does not figure very largely in the expenses.

As practical tests are more satisfactory than theory, the writer requested Mr. Hardie to make a test of the consumption of air at different speeds, and report the result. The following is the report, under date of April 22, 1896:

FIRST TEST. LOAD, 19,150 POUNDS.

Speed.						*Cubic Feet per Mile.*
3·00	miles	per	hour,	consumption	of air	347
5·70	"	"	"	"	"	334
6·81	"	"	"	"	"	488
7·57	"	"	"	"	"	335
7·80	"	"	"	"	"	568
8·50	"	"	"	"	"	452
9·70	"	"	"	"	"	388
10·10	"	"	"	"	"	560
10·30	"	"	"	"	"	275
11·40	"	"	"	"	"	604
12·30	"	"	"	"	"	421
13·00	"	"	"	"	"	538
13·70	"	"	"	"	"	447
16·70	"	"	"	"	"	450
17·05	"	"	"	"	"	447
22·80	"	"	"	"	"	445

SECOND TEST. LOAD, 24,990 POUNDS.

12·27	miles	per	hour,	consumption	of air	334
15·34	"	"	"	"	"	449

THIRD TEST. LOAD, 26,100 POUNDS.

6·70	miles	per	hour,	consumption	of air	437
8·00	"	"	"	"	"	452
10·34	"	"	"	"	"	470

FOURTH TEST. LOAD, 36,000 POUNDS.

5·25	miles	per	hour,	consumption	of air	632
7·50	"	"	"	"	"	582
8·56	"	"	"	"	"	589
15·34	"	"	"	"	"	334

The above results are very remarkable. The ordinary pressure gauges are not very sensitive, but it is impossible, from the above table, to infer that there was any increased consumption of air per mile, either with a largely increased speed or a considerable increase of weight. When a train is in motion, the draw-bar pull is but slightly increased by a moderate increase of speed. The great losses of power are in acceleration and retardation in starting and stopping.

It has been stated that the power required on a good track to start a street car is 116 pounds per ton, and to maintain it in motion 13 to 17 pounds. On a bad track, 134 pounds to start and 35 pounds to maintain.

Mr. Hardie has found by tests upon his motor that 130 successive applications of the brake consumed, by gauge pressure, 85 cubic feet of free air, equivalent to 0·65 cubic feet for each application.

Franklin L. Pope is authority for the following statement:

"A 16-foot trolley car, weighing about 14,000 pounds, requires eighteen seconds to get up speed and 10 horse-power to run 10 miles per hour, or 1 horse-power per mile per hour at car axle. Three times this power is required during the eighteen seconds of starting."

Frank S. Sprague, in New York *Evening Post*, of February 8, 1896, states that on the Third Avenue Elevated Railroad the maximum effort in the propulsion of trains is seven times the mean traction on a level; and that to start a train, accelerate to 20 miles per hour and bring it again to rest, consumes eighty seconds.

David L. Barnes estimates that an elevated train of 130 tons can be accelerated to 30 miles per hour in a distance of 1,250 feet, and brought to rest in half that distance.

OTHER USES FOR COMPRESSED AIR.

Compressed air affords the most economical means for the transmission of power to long distances. It has been claimed that electrical power generated from waterfalls could be transmitted hundreds of miles, but the writer has attempted to show in a monograph that is too voluminous to quote, that in the present condition of the science, power by electricity cannot be economically transmitted in competition with power furnished locally by coal, to a greater distance than about 20 miles. Long electrical transmission requires excessively high voltages, which are almost impossible of permanent and successful insulation, and instantly destructive to life in case of accidental contact. The late lamented Franklin Leonard Pope, in a letter to the writer, used this language: "A voltage of 20,000 may be possible in the future, but it has not yet been successfully accomplished. The difficulties seem to increase roughly as the square of the voltage; 10,000 volts is a wicked acting current, and when you double it, you had better watch out." He also adds: "The same speculative boomers who have put in 300 non-paying electric railroads throughout the country are now at work fostering a craze on electric power transmission. I am sorry to see it, for it will end in discrediting all legitimate electric work. The mass of people will never learn to discriminate between the practicable and impracticable."

The transmission of compressed air requires high pressures, for the reason that increased pressure gives increased density and reduced volume and velocity. The loss in transmission being as the first power of the density and the square of the velocity, the loss in transmitting under 200 pounds would be ten times as great as under 2,000 pounds. High pressures are necessary for economical transmission both with electricity and air.

But compressed air and electricity are not properly to be considered antagonists; they may be made valuable auxiliaries.

A 6-inch pipe under an initial pressure of 2,000 pounds per square inch, and a terminal pressure of 10 atmospheres, or 147 pounds, will transmit nearly 8,000 horse-power to a distance of 10 miles, 5,700 horse-power to 20 miles, and 2,500 horse-power to a distance of 100 miles. Where there are mountain streams furnishing small powers at frequent intervals, a number can be concentrated in one pipe, and transmitted to furnish large power in distant localities. Compressed air, thus economically transmitted, can be used to generate electricity for local purposes. It can also be distributed to provide small powers, and also for ventilation and refrigeration in towns and cities.

The cable and electric systems, it is well known, are operated to best advantage economically at full capacity, but this is only for a few hours in the day. If surplus power were used to store air at high pressure in reservoirs the machinery could be shut down entirely or partially, and compressed air motors substituted at night and during the hours when full capacity is not required.

ELASTICITY OF THE SYSTEM.

An important advantage of compressed air motors is found in the fact that each motor is independent, and unaffected by any derangement of feed or trolley wires, cables or dynamos. They can run on any line, in connection

with any other system, and at any rate of speed. The introduction of air motors can be gradual; one motor can be tried, and, if satisfactory, the number can be increased to a full equipment. The steam required for electric or cable lines can furnish the little that is required for an experimental compressor, and will be more than sufficient for a full equipment. No outside expenditure whatever is required—no conduits, poles or wires. In this respect it differs from other systems, and permits a test to be made at a minimum of cost; but compressed air motors can no longer be considered as experiments. While they may not have attained the utmost limit of perfection of which they are capable, the experience in Europe, in Rome, N. Y., and in the City of New York, should be sufficient to satisfy the most skeptical.

THE AUTOMOBILE

A PRACTICAL TREATISE ON
THE CONSTRUCTION OF MODERN MOTOR CARS
STEAM, PETROL, ELECTRIC AND PETROL-ELECTRIC

EDITED BY PAUL N. HASLUCK

VOLUME I

BASED ON LAVERGNE'S "L'AUTOMOBILE SUR ROUTE"

The suggested substitutes for the three above agents will now be considered, taking in the first place gas under pressure and compressed air. As regards air, its native density, even under heavy pressure, is very slight, and enables it to accumulate considerable energy; 1 kg. of air compressed at 45 atmospheres is equivalent to not less than 20,765 kgm. (68,110 ft.-lb. per lb.). It must, however, be confined in a receptacle weighing thirteen times more than itself, so that the specific power of this same confined air is not more than 1,608 kgm. (11·600 ft.-lb.). This cannot compare with 4,250,000 theoretic kgm. and 250,000 kgm. effective at the wheels given by 1 kg. of petroleum (13,940,000 ft.-lb. and 1,190,000 ft.-lb. per 1 lb.). As regards practical employment of compressed air, its use on public tramways will be familiar. The air compressed at 45, 60, and even 90 atmospheres, by aid of a special apparatus, which must be prevented from heating, is carried in receptacles on the car. The compressed air does work by its expansion in the motor cylinder, but as this expansion would be followed by cooling and formation of ice in the cylinder and exhaust pipes, the compressed air must be heated before use, by making it bubble through hot water, or by passing through heated pipes. All this certainly complicates the use of compressed air as regards automobiles, but its use is possible for tramcars which, whilst always running along the same road, and periodically returning to the charging stations, are sufficiently big to carry heavy receptacles containing the fluid. Finally, the decrease of traction strain offered by the rails and the number of passengers simultaneously transported make the cost per car-kilometre or per car-mile reasonable, though still relatively great. (With the Mekarski tramways of Paris and Nantes, whose cars each weigh 12 tons and carry 50 passengers, the cost per car-kilometre is 3·3d., that is, 5·3d. per car-mile; in the former figures, the compressed air is represented by 1·9d., repairs of pipes 0·70d., and repairs and lubrication of the car, 0·67d.)

This would not be feasible for an automobile which must find supplies easily and has not space to carry sufficient tanks for a long journey; and consequently, in spite of its real advantages as regards cleanliness, ease of starting and stopping by aid of a valve, and the

impossibility of fire, this system of propulsion does not seem to be suitable for automobiles: this fact explains the failure of experiments. W. Mann in 1822, Wright in 1830, and Fordham in 1832, prepared plans for compressed air automobiles which have never been executed. In 1840, two French engineers, Andraud and Tessié du Motay, built the first compressed air car, and on July 9th of the same year it made a trial trip at Chaillot on a railway track; its structure would have enabled it also to run on roads, but there is doubt whether it ever ran on any other occasion than that mentioned. Recently, Hartley of Chicago constructed a tricycle with a reservoir between the two front bearing and steering wheels. This air container drove a two-cylinder motor, which transmitted its motion by means of two chains to the rear driving-wheel. An average speed of 12·8 km. (8 miles) an hour was obtained; but though the Chicago postal authorities endeavoured to substitute it for some of their ordinary cars, it is not thought to have much of a future, even for purely city service. Ravel states, in a French publication, that this system, tried about 1888 on a tramway, showed a loss of 70 per cent. by the transmission gear.

Finally, at the Paris Salon of 1899, the firm of Molas, Lamielle, and Tessier exhibited a heavy goods vehicle; but, though it may be regarded as the medium between the light car, for which the employment of air seems impossible, and the tramcar, for which it is used daily, it is not believed that this application will lead to anything. The vehicle in question, originally constructed for animal traction, was adapted with only the minimum number of alterations actually required for its new use. The air supply is said to be carried in bottles made of a special kind of soft steel, which does not burst, but tears like lead when the pressure is too great to be withstood. Some further particulars should be given of this steel, which so surely obviates the danger of storing gases compressed until they give a pressure of not less than 300 kg. per cm.^{2} (4,270 lb. per sq. in.). Many tramcars in France employed air compressed to only 45 atmospheres, and in any case it is not believed that the pressure in the above case exceeds twice that, whereas Molas, Lamielle, and Tessier make it more than six times. In America, it is said, the air is now compressed to this pressure. A suitable expansion brings the compressed air to the pressure at which it is employed in the cylinders, namely, 60 kg. to 4 kg. per cm.^{2} (854 lb. to 57 lb. per sq. in.), and the precautions taken to prevent the formation of ice are not stated. The motor, composed of four single-acting cylinders, is placed with its adjuncts in the car, under the driver's seat, out of the way of mud and dust; and the makers say that a special system of distribution enables the air to be employed to within the last few cubic centimètres. Normally, the motor makes only 280 revolutions per minute, and from 1 h.p. to 35 h.p. can be obtained. The four pistons directly drive the intermediary shaft carrying the little sprocket wheel, which, by means of chains, impels the driving

wheels, these being at the back of the vehicle, and furnished with sprocket pulleys: a stretcher, said to be similar to two guide rollers, keeps the chain links in the pockets intended for their reception. Steering is made possible by means of a pivoted fore-carriage. The constructors give the following figures:—

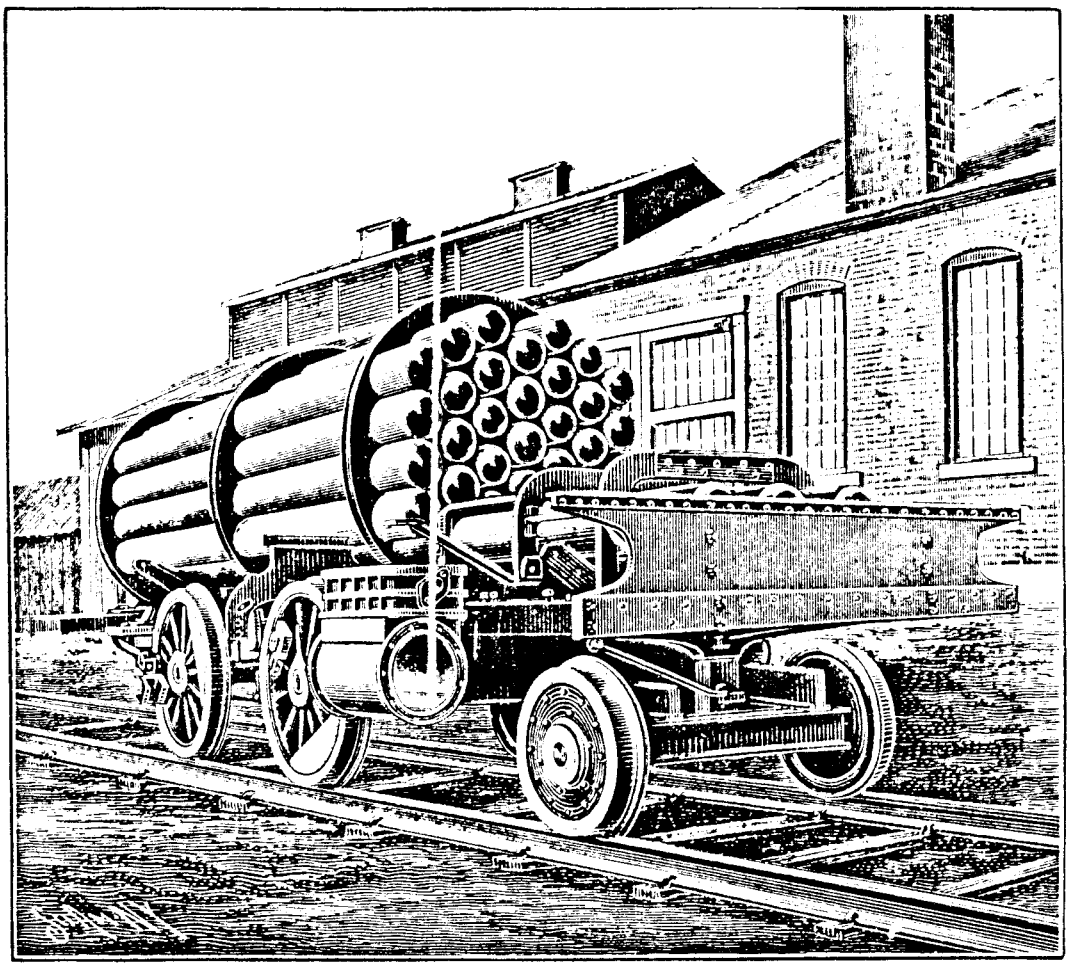
Weight of car	1,400 kg. ...	3,080 lb.
„ „ motor and adjuncts	450 kg. ...	990 lb.
„ „ compressed air tanks	1,050 kg. ...	2,315 lb.
„ „ car in running order...	2,900 kg. ...	6,500 lb.
„ „ useful load	2,000 kg. ...	4,410 lb.
„ „ useful load compared with total weight of loaded car...	40·8 per cent.	
Speed per hour	10 km. ...	6·2 miles.
Cost of motof car	10,000 fr. ...	£400.
Cost price per ton per kilometre for daily journey of 50 km. (31 miles)	*0·295 fr. ...	2s. 8d.
Cost price per ton per kilometre for daily journey of 100 km. (62 miles)	†0·196 fr. ...	1s. 8d.

* 1s. 7d. per ton per mile. † 1s. 1d. per ton per mile.

These figures show greater economy than those obtained in the Versailles competition in 1897 (*see* p. 767), but they cannot be compared legitimately until they have been verified by tests made and controlled as carefully as those of the competition. Until then, it will be more economic, it is thought, to burn coal in the boiler of an automobile than in that of a compressor to feed the car.

JANUARY 30, 1897

COMPRESSED AIR MOTOR ON THE ELEVATED RAILROADS, NEW YORK.



VIEW OF MOTOR IN COURSE OF CONSTRUCTION, SHOWING BATTERY OF COMPRESSED AIR STORAGE FLASKS.

Compressed air, considered as a motive power, affords a striking evidence of the pertinacity with which a prejudice, which has been engendered by early failures in any line of experimentation, will cling to it in subsequent attempts. At least so it would seem, if one should judge by the ever recurring predictions of failure which greet the arrival of a new design of compressed air motor. These predictions are usually prefaced with the statement that the defects of compressed air are inherent in the application of the principles upon which it works, certain physical laws rendering it impossible that a high efficiency can be achieved.

That the early attempts were doomed to failure because of an extravagant loss of power between the compressor and the motor cannot be denied; but that the defect should be set down as permanent and without remedy is to cast discredit upon the resources of science and mechanics. So far from the course of invention in this particular field being of the blind and uninstructed kind, it has been carried out on scientific lines and marked by an intelligent investigation which will compare favorably with that in any other field of experiment.

In the early and faulty use of the system, air was compressed and stored in a receiver, from which it was drawn for use in the cylinders of the motor. It was found that the mean pressure available behind the piston of the motor was very much less than the mean pressure at the air piston of the compressor. So great was the loss that in some of the plants it is acknowledged to have amounted to between fifty and sixty per cent. The difficulty was due to a natural law governing the contraction and expansion of air, according to which its sudden compression is marked by a sudden rise in temperature, and its sudden expansion being followed by a corresponding fall. If a given volume of free air be compressed to one-half, its temperature will be raised 116 degrees; on the other hand, if a given volume of free air be expanded to twice its original volume, its temperature will fall 116 degrees. If air be compressed in unjacketed cylinders, the attendant heat will be communicated to the walls of the cylinders and lost by radiation, and what heat is not lost in this way will escape by radiation from the storage tanks, as its temperature falls to that of the surrounding atmosphere. Again, the expansion of the air in the motor cylinders will be attended with a corresponding fall of temperature, which, according to law, will be accompanied by a decrease in volume and, therefore, in pressure, this decrease in pressure being additional to that which results from the expansion of the air due to the travel of the piston. There will thus be a loss at both ends—that at the compressor due to the generation of heat and that at the motor due to its dissipation. There will also be the mechanical disadvantage that, the temperature of the exhaust being considerably below the freezing point, the passages are liable to be clogged with ice.

These are the fundamental difficulties which threw discredit upon the first attempts to use compressed air as a motive power, and led to the sweeping assertion that it was inherently and essentially uneconomical. Subsequent experiments in Europe and America have shown, however, that by the application of heat to the air on its way from compressor to motor, its efficiency may be largely increased, and in the various street car motors now running in both countries this reheating is invariably carried out. The system adopted by the builders of the motor which forms the subject of the accompanying illustrations consists in passing the compressed air through a tank of hot water before it is used in the cylinders. There are certain other economies attending the compression at the power station and the utilization of the exhaust steam which altogether render the plant of the Hardie motor of special scientific and technical interest. One of the most marked advances over the old systems is seen in the extremely high pressure (2,000 pounds to the square inch) at which the air is stored in the tanks. This has been adopted because of the valuable and opportune property of air that under high pressures a certain increase of pressure calls for

less power and produces less heat than under low pressures. It has been found that to compress 1 cubic foot of free air to 500 pounds pressure per minute requires 0·316 horse power, whereas to compress the same amount of free air to 2,000 pounds pressure requires only 0·400 horse power, though it is deemed advisable to allow 0·45 horse power in practice. The heat of compression is saved by compressing the air in three stages, and passing the heated air through tubes around which cold water is circulating. The air-cooling water is fed to the boilers, and the heat which it has withdrawn from the compressed air is thus recovered. The compressed air is stored in a nest of rolled steel flasks at the normal temperature of the atmosphere, and from them is supplied to a similar nest of flasks carried on the motor.

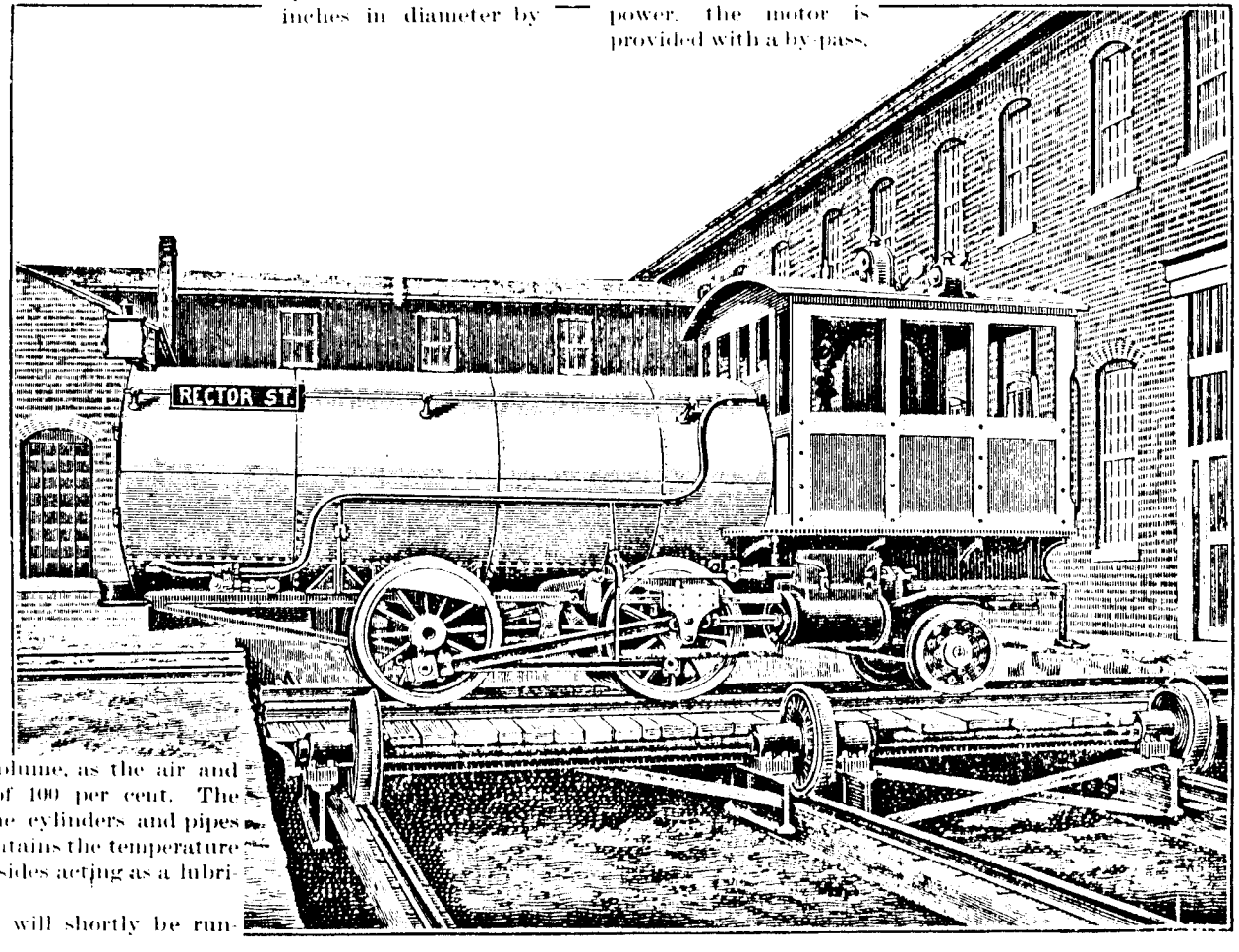
The reheating of the air is accomplished by passing it at the working pressure of 150 pounds to the square inch—to which it is brought down by a reducing valve—through a tank of water heated to 350 degrees, which is carried on the motor and recharged at the end of each trip. In its passage through the hot water, the air is not only expanded by the increase of temperature by fifty per cent of its original volume, but it absorbs and carries over to the cylinders an amount of water, in the shape of steam, equivalent to half its own original volume. Thus each fifty cubic feet of air admitted from the storage flasks takes up half its own volume of steam, or twenty-six cubic feet—an increase of over fifty per cent; and as it also receives an increase of volume of fifty per cent due to increase of temperature, there is a total gain of volume, as the air and steam pass from the heater, of 100 per cent. The condensation of the steam in the cylinders and pipes liberates the latent heat and maintains the temperature well above the freezing point, besides acting as a lubricant in the cylinders.

The experimental motor which will shortly be running on the elevated roads differs materially in appearance from the steam locomotives now employed. The boiler of the latter will be replaced by a stack of 36 tanks or flasks, 9 inches diameter by 15½ feet long, inclosed in a sheet iron casing. The familiar steam dome and smokestack are wanting; the sand box being placed as at present below on the frame. There are four coupled driving wheels, and the cylinders, which are 13½ inches in diameter by 20 inches stroke, are placed directly beneath the cab. These, it will be seen, are considerably larger than those of the present locomotives, which are 12 inches diameter by 16 inches stroke. Altogether the new motor will be a much more powerful machine.

On a line with such frequent stops as the elevated road, rapidity in starting is a consideration of the first importance. In addition to its increased cylinder power, the motor is provided with a by-pass, by which air may be admitted to the cylinders independently of the slide valve. The motor is thus provided with a reserve of tractive effort which will save several seconds each time the train is started and will result in a saving of several minutes on the round trip.

From the above description our readers will be able to secure a general idea of the principles and construction of the new motor, which is about to contest the supremacy of the steam locomotive under conditions which will provide "a fair field and no favor." Judging from the results obtained with the Hardie motors which are running on the lines of the Third Avenue company in this city, it is reasonable to expect that the new motor will not suffer in the comparison. The first two of these cars, which were put in service on August 3, 1896, have now run about 20,000 miles and carried 125,000 passengers. During the heaviest snow storm of this winter they ran 153 miles on time, their service comparing favorably with that of the cable cars.

How far the same efficiency can be shown by the heavier motors, and how far they can show superior economy to the steam locomotive, will now be determined by a lengthy and careful test.



COMPRESSED AIR MOTOR FOR THE ELEVATED RAILROADS NEW YORK CITY.

COMPRESSED AIR AND ELECTRIC TRACTION ON NEW YORK STREET RAILWAYS.*

The underground trolley system of electric propulsion for street surface roads has now had a year's trial on the Lenox Ave. line of the Metropolitan St. Ry. Co. in New York city, and although not quite as satisfactory or economical as the overhead trolley, is regarded as preferable to the cable in so many respects that its use is to be extended to other longitudinal routes of this company. In view of this fact it is safe to predict that there will be no more cable construction in New York city.

Some very satisfactory experiments have been made recently with compressed air as a motive power. Three Hardy compressed air cars, manufactured at Rome, N. Y., have been in operation on the 125th St. line of the Third Ave. R. R. Co. since Aug. 1, 1896. The cars are run across 125th St. from the Fort Lee ferry to the East River, a distance of a little over two miles. They are charged every three round trips, thus giving them a run of about 13 miles. The heaviest grade is about 8%, near Fourth Ave. The compressor plant is located at the car barn. An 80-HP. engine compresses the air into a battery of storage tubes at 2,000 lbs. pressure, and the air is carried through a pipe to a point in the barn where the car is charged, about two minutes being required for the operation. Two cars are constantly in service. The third stands at the barn ready to take the place of a car requiring to be recharged. Each car holds 52 cu. ft. of air under a pressure of 2,000 lbs. The working air pressure as applied to the motor averages about 130 lbs. During the December snow storms the cable cars were blocked on the 125th St. line while the air cars had no difficulty in making time when not interfered with by the other cars. It is claimed by the inventor of this system that the cost of operation per car mile will be less than the overhead trolley system. The limited operation on 125th St., however, does not furnish sufficient data for accurate conclusions.

The Hoadley compressed air system is being experimented with by the Metropolitan St. Ry. Co. on its Lenox Ave. line between 110th and 146th St. with apparent success. The chief difference between these two compressed air systems is in the method of applying the power. The Hardy motor has cylinders and piston acting directly upon the axle as in the case of a steam locomotive. In the Hoadley motor the power is applied by gearing.

The Manhattan Elevated R. R. Co. intends making experiments with the Hardy motor. The motor company is now building an engine at Rome about the size of the steam engines at present in use on the elevated railway. It will be operated on the Sixth Ave. line, between Rector St. and 58th St., the compressor plant being located at Rector St. The engine will be constructed to carry sufficient air to operate a train of five cars 13 miles without recharging. It is expected that the engine will be ready for service some time in February.

The elevated railway company has also been trying electricity on its 34th St. branch, from Third Ave. to the 34th St. ferry. The motor was built upon the trucks of a dummy engine. A third rail, which conducts the current from the power house to the motor, has been placed on insulated chairs fastened to the guard timbers outside the track rail and standing about 10 ins. above the track rails. The connection is made by two steel shoes which reach from the lower side of the motor and clasp the charged rail. When more electricity is produced than is used by the motors it is stored in accumulators located at the ferry end of the route. This motor has been successfully working since Oct. 5. The average power, including heat and light for the cars, is 45 amperes; voltage 450. No difficulty in operation was experienced during snow storms, and mechanically the motor has done all the work required of it. Regarding its economical efficiency, the line is too short and the traffic too limited to admit of comparisons that would be of much value.

*Extract from the report of the Board of Railroad Commissioners of New York State for 1896.

Compressed Air Motors in New York.

The fact that two compressed air motor cars belonging to the American Air Power Company have been in operation for some time in New York City, is known to the readers of the STREET RAILWAY JOURNAL through articles in former issues. In the last issue of "Compressed Air" a report of their operation is given by E. E. Pettee, engineer of the American Air Power Company. The following statements are taken from this report:

The 125th Street line of the Third Avenue Railroad extends across town from the North River to the Harlem River, the length of the tracks being 10,854 ft., making the round trip 4.11 miles, over which cable cars are operated at intervals of 2½ minutes. Air cars were substituted for two of these cable cars, the schedule calling for nineteen round trips each, of 79.09 miles per car; for a daily service of 156.18 miles besides 1.14 miles of switching to and from the car house and street tracks, making the total distance covered daily, 157.32 miles. Each car runs from 12.50 to 16.67 miles on a single charge of air.

During a portion of the time, only single service was performed, as at present, so that the total average mileage per day from Aug. 3 to Mar. 3, was 125.16 miles, the total distance covered, 23,030.5 miles, and the total number of passengers carried, 137,386. The cars have operated every week day, but are not run Sundays.

The grade from Fort Lee Ferry east to the Boulevard is 1.96 per cent, while at the New York Central Railroad tunnel crossing, the maximum grade is 7.7 per cent for a short distance.

In the following statement of operating expenses, the coal and water items include all that has been used at the compressing plant during this period, and the labor account includes, in addition to the operating employes, a night watchman, record keeper, and also switchman for a portion of the time. It must also be borne in mind that the fires are kept under boilers for twenty-four hours, although the compressor only runs seven hours daily.

Actual average cost per car mile for entire period—seven months—125.16 miles per day.

Coal	$.0563
Water	.0103
Oil and waste	.0013
Power plant labor	.1261
Conductor and motorman	.0608
Repairs car equipment	.0038
	$.2586

Average present cost per car mile, with one car service performed—78.09 miles per day.

Coal	$.0675
Water	.0113
Oil and waste	.0017
Power plant labor	.0833
Conductor and motorman	.0608
Repairs, car equipment	.0038
	$.2284

Average present cost per car mile, with two car service—156.18 miles per day.

Coal	$.0433
Water	.0103
Oil and waste	.0013
Power plant labor	.0833
Conductor and motorman	.0608
Repairs	.0028
	$.2018

If the proportion of labor actually utilized in this service is considered, the expense would only amount to $0.1791 per car mile at present.

The present number of employes is six, besides conductors and motormen.

The reason for the present cost of operation being lower than the average for entire period is that the number of employes has been reduced as well as the air consumption by the car. The number of employes at present is, however, sufficient to operate a fifteen car service, so that the proportion of labor charges per car mile is still very high.

At a recent conference of several engineers, who investigated the cost of operating the American Air Power Company's system in behalf of a street railway now operating a large number of cars at intervals of one minute, it was determined after careful examination

and agreed that for the items above enumerated, the cost per car mile would in no event exceed $0.085, and that with a large equipment of cars in service, like that performed on 125th Street, the cost would only be $0.0756 for the same items now costing $0.2018, while operating the two car service. This would make the total operating expense of such a road about twelve cents per car mile.

The average consumption of free air per car mile for the seven months' service of air cars on 125th Street, has been 477.7 cu. ft. During the severe snow storm of Dec. 16, 1896, the cars performed the schedule service with promptness and regularity, carrying 20 per cent more passengers and using 22 per cent more power than the day previous. In comparing results with an electric road in this vicinity, it appears that with 33 per cent less service than the day previous, the load on the power plant was about 80 per cent greater.

During the last week, the average consumption of free air per car mile was only 414 cu. ft., and many of the trips were made on considerably less than 400 cu. ft.

The actual cost of compressing air to 2500 pressure per square inch, and storing for use in a modern air compressing plant operating with condensing engines, including coal at $2.75 per ton, water, at $1 per thousand cubic feet, oil and waste, the removal of ashes, labor, repairs and maintenance of power plant, depreciation, and interest on cost of entire power plant, including buildings, for compressing plants of the following capacities, based on the consumption of 2½ lbs. of coal per hour, per horse power for twenty hours per day, is estimated as follows:

Cost per 1000 cu. ft. of free air compressed to 2500 lbs. pressure per square inch.

STATION CAPACITY.

500 cu. ft. per minute	$0.0675
1000 " "	.0571
2000 " "	.0469
3000 " "	.0419
4000 " "	.0394
5000 " "	.0375
6000 " "	.0359
7000 " "	.0342
8000 " "	.0326
9000 " "	.0312
10000 " "	.0300

The process of operating the compressed air system on 125th Street, is as follows:

The air is first compressed by a steam actuated air compressor, which is compounded in three stages from which the air passes through a cooler and dryer and is accumulated in a nest of Mannesmann steel flasks which are all connected in multiple by a series of headers or manifolds, in which stop valves are placed for controlling and confining the air to be stored at a maximum pressure of 2500 lbs. per square inch. A pipe leads from this air storage to the car house charging stand, placed alongside the track, which consists of a copper pipe in three sections, having a controlling valve and flexible joints and a charging nozzle at the end. All the joints and the nozzle are self packing so that no leakage has occurred in the seven months' service. After the car has been connected by inserting the nozzle in a pipe at the side of the car track, the charging valve is opened and contents of the station storage flasks admitted until the desired pressure—2000 lbs. per square inch—is registered by the car storage gage. When the charging valve is closed and a small bleeding valve in the charging pipe opened, permitting the high pressure air in the short length of pipe to escape, at the same time a check valve in the car piping closes automatically preventing any escape of air, after which the nozzle is removed and the car ready for another 17 miles' service. The entire time occupied, including connecting and disconnecting in actual daily service, takes less than two minutes, and has been done in less than one minute in numerous trials.

At the same time the car is being charged with air, another nozzle is introduced to the heater connection, and live steam from the boilers is admitted, until the temperature registered is about 300 degs. F.

The air storage reservoirs on these cars have a capacity of 51 cu. ft., sufficient to run the car 18 to 20 miles continuously, or from 14 to 17 miles, making the stops incident to ordinary street railway service. A larger capacity could readily be installed on the car, giving it ample power to run 20 miles with a reserve. The reservoirs consist of seamless steel flasks capable of standing a pressure of double that used without reaching the elastic limit of the metal and with no possibility of leakage. They are 9 ins. in diameter and of varying lengths adapted to their location under the seats and the car floor. Between the flasks and the motor is placed a small tank containing 6 cu. ft. of water which is heated as before described. The tank is jacketed with non-conducting material, preventing external radiation. This provides not only against loss of heat, but also against any perceptible rise in the surrounding atmosphere, so that no discomfort can arise from it.

Numerous trials have proved that the application of heat as employed in this system enables the cars to run nearly double the distance that cold air will carry them.

In operation, the compressed air, after passing through a reducing valve and being lowered to 150 lbs. to the square inch (the working pressure), circulates freely through the hot water, and a mixture of heated air and vaporized water passes to the motors, working expansively, the terminal pressure being so low as to cause no sound in exhausting the air.

The motor mechanism consists of two simple, link-motion reciprocating engines having cylinders 7 ins. in diameter and 14 in. stroke, with valves cutting off at from $\frac{1}{10}$ to $\frac{1}{8}$, and applying the power by connecting and parallel rods direct to the crank pins of the drive wheels, which are four in number, 26 ins. in diameter running on a wheel base of 7½ ft. Upon this four wheeled truck rests the entire weight of the car and mechanism, evenly distributed upon elliptic springs, enabling the car to pass smoothly over bad track and crossings.

The mechanical features of the motors are substantially identical with those of a steam locomotive, minus fire box and boiler.

The car is fitted with specially designed air brakes of sufficient power, with the high pressure air always at command, to set the wheels instantly if desired, by a single wrist movement of the motorman.

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Compressed Air Motors in Washington.

The Eckington & Soldiers' Home Railway Company, of Washington, D. C., has in operation one of the Hoadley-Knight compressed air motor cars. The car carries the air under a pressure of 2000 lbs. per square inch in thirty-four reservoirs, and all machinery is located under the car. Mr. Schoepf, the receiver of the Eckington & Soldiers' Home Railway Company, states that the results have been so satisfactory that fifteen cars have been ordered and also a compressor.

Mr. Schoepf is quoted as saying that "No disinterested observer who has watched the tests over the Eckington lines that have been conducted for some time past can have any other than my own opinion about the reliability and success of compressed air for street car propulsion."

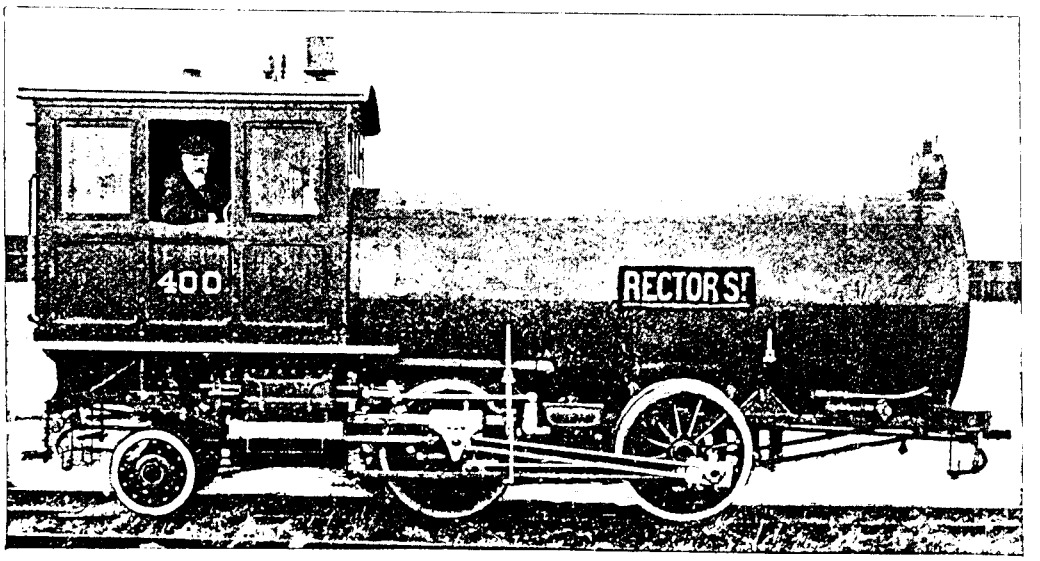
Compressed Air Motors for Elevated Railroad Service.

The accompanying engraving shows a new compressed air locomotive recently built by the American Air Power Company for the Manhattan Elevated Railroad Company of New York. The locomotive will be put in operation within a few days on the Sixth Avenue division of that company and will operate between Fifty-eighth Street and Rector Street.

The wheels are 42 ins. in diameter; the dimensions of the cylinder are 13 ins. in diameter by 20 ins. stroke, and the storage reservoir has a capacity of 175 cu. ft. This, it is estimated, will allow the locomotive to make the round trip between Rector Street and Fifty-eighth Street with 20 per cent reserve. The reservoir is composed of Mannesmann tubes with a diameter of 9 ins. and having various lengths, from 14 ft. to 20 ft. 6 ins. The thickness of the tube is 9 ins. The tubes are rolled from solid ingots according to the regular Mannesmann process.

The air is stored in the reservoir at 2000 lbs. pressure. It is used in the cylinder at 200 lbs. pressure with cut-off at $\frac{1}{10}$ stroke. In passing from the reservoir to the cylinder it traverses the usual hot water reheater and enters the cylinder at a temperature of from 200 to 300 degs. The water is kept heated by a small coal fire. But little fuel is required to maintain this, as will be appreciated when it is stated that only an ordinary scuttleful of coal is carried by the engine.

A novel feature of the engine, as will be seen, is the location of the cylinder. This is directly under the cab, giving a short lead for the heated air. The valve mechanism is extremely simple and can be seen in the engraving under the cab. It is operated by the wheel which can be seen through the window of the cab. The weight of the entire locomotive equipped is 47,000 lbs. The power station will be located at 100 Greenwich Street.



COMPRESSED AIR LOCOMOTIVE FOR NEW YORK.

THE HARDIE COMPRESSED AIR LOCOMOTIVE FOR THE MANHATTAN ELEVATED RY.

Compressed air has for many years been in limited use as a motive power for small locomotives and motor cars for mine work and in street railway service; but the last two or three years has witnessed a revival of interest in this form of motive power on the part of inventors and investors, which is resulting in a more extended trial of this class of motor than has ever before been given to it. The chief difference between the recent work in compressed air locomotion, and that which was done in former years is the use of a very much higher pressure in the storage tanks, roughly about 2,000 lbs. per sq. in., against some 300 lbs. to 600 lbs. in the older experiments. The result is, of course, the storage of a much larger amount of power in the same bulk, which means that a motor car with air storage tanks of a given size can run a much longer distance between chargings than was formerly the case.

What is doubtless the most ambitious attempt at compressed air locomotion for railway service that has ever been made is the construction of a compressed air locomotive for the Manhattan Elevated Ry. in New York city.

This locomotive was built by the New York Locomotive Works, of Rome, N. Y., to the designs of the inventor, Mr. Robert Hardie, Chief Engineer of the General Compressed Air Co., and it is being operated by the American Air Power Co., of New York. We are indebted to Mr. E. E. Pettee, Chief Engineer of the latter company, for the photograph and drawings of the engine from which our illustrations are prepared. It is true that a Hardie engine was tried on the Second Ave. line of the elevated railways in 1881, but at that time the storage pressure was only 600 lbs. per sq. in., while in the new engine a pressure of 2,400 lbs. is made practicable by employing Mannesmann rolled steel tubes for the air reservoir.

As will be seen by the general view in Fig. 1, the new engine somewhat resembles the steam locomotives of the elevated railways, but it has neither smokestack, tank nor coal bunker, and has

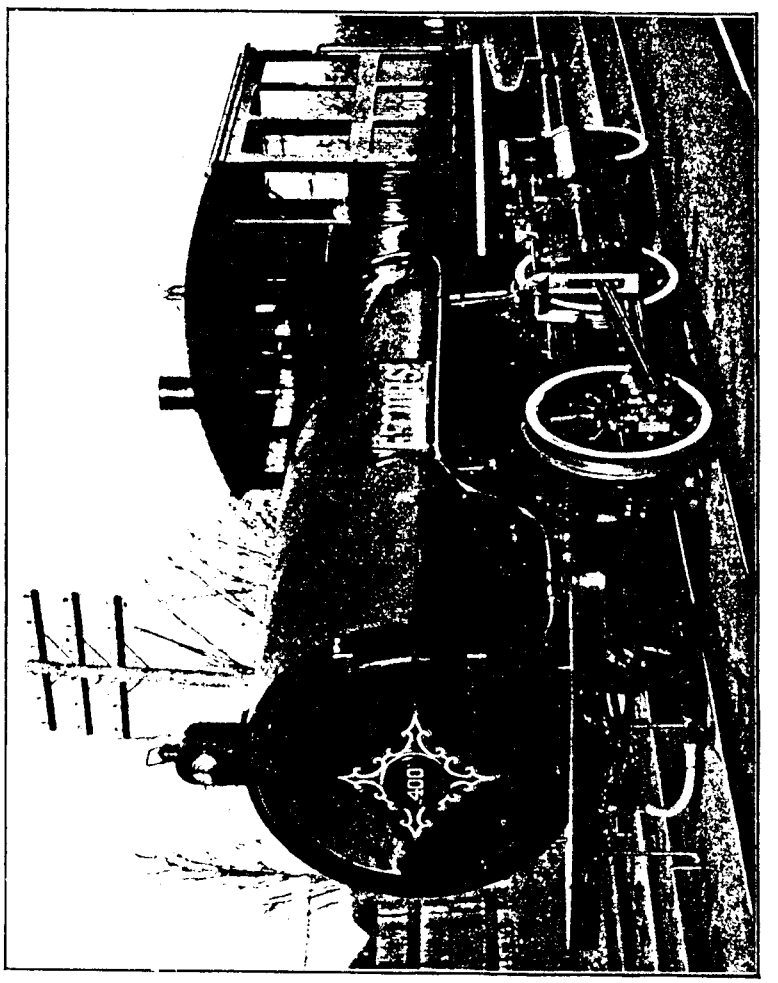


FIG. 1.—HARDIE COMPRESSED AIR LOCOMOTIVE FOR THE MANHATTAN ELEVATED RAILWAY.
American Air Power Co., Owners; New York Locomotive Works, Builders.

a two-wheel instead of a four-wheel trailing truck, and the cylinders are placed under the cab. The air reservoir, which occupies the place of the boiler of a steam locomotive, consists of a set of 27 Mannesmann rolled steel tubes, 9 ins. diameter and 15 ft. 6 ins. long, all enclosed in an ordinary boiler jacket. The drawings show 37 tubes, but the engine, as actually built, has only 27 tubes. The nipples on the front ends of these tubes are fitted with pipes, each set of pipes being connected to a main pipe leading to a vertical header, from the base of which two pipes lead to the pressure-reducing valves, which reduce the pressure to 150 lbs. per sq. in. From these valves the air passes to a vertical reheater in the cab, having a capacity of about 50 gallons of water, which is heated by a small stove at the bottom. The air then passes to the cylinders. The slide valves are operated by a Stephenson link motion, with a Meyer adjustable cut-off, operated from the crosshead. The cut-off may be set at from one-tenth to half-stroke by means of a hand-wheel in the cab, connecting with the admission valve. In starting, it is not necessary to alter the position of the cut-off valve, as a by-pass valve can be opened to effect a connection between the low-pressure receiver and the cylinders, the air entering by the small pipes shown on the valve chest. This valve is opened by pushing the brake handle beyond the point at which it releases the brakes, and as soon as this is done the throttle valve is opened and the engine has ample starting power, regardless of the position of the cut-off. Increased pressure for starting may be obtained by pushing the brake handle still farther forward, thus operating a device on the reducing valve and allowing air to enter the cylinders at a pressure one-third greater than the normal working pressure. When the engine has fairly started, the brake handle is moved back to its running position, leaving the engine to work under normal conditions.

A special air-brake is used for the driving wheels, and the Eames vacuum brake on the train will be operated, as at present, except that the ejector will operate by an air jet instead of a steam jet. The locomotive is designed for a maximum train load of about 130 tons, and the highest recorded speed is 45 miles per hour.

The compressing plant is situated at 100 Greenwich St., near Rector St., and is operated by a 230-HP. Corliss engine, built at the Cooper Works, Mount Vernon, O., and having cylinders 16 x 36 ins. This engine drives a quadruple air compressor built by the Ingersoll-Sergeant Drill Co., of New York city, having cylinders 3, 7, 9 and 21¼ ins. diameter and 36 ins. stroke, and being capable of delivering 500 cu. ft. of free air per minute, compressed to a pressure of 2,500 lbs. The storage reservoir consists of a nest of Mannesmann rolled steel tubes, with a capacity of 820 cu. ft., in which the air is stored at a pressure of 2,550 lbs. The locomotive is charged by means of a self-packing, flexible metallic connection, the time occupied in charging being about 1 minute.

The general dimensions of the locomotive are as follows:

Driving wheels, diameter	3 ft. 6 ins.
Journals, driving axles (hollow), diameter	5¾ "
" truck axles, diameter	4 "
Wheelbase, driving	6 ft. 0 "
" total	13 " 6 "
Truck pin to c. of leading driving axle	7 ft. 6 ins.
Weight in working order:	
On driving wheels	36,000 lbs.
On truck wheels	11,000 "
Total	47,000 "
Cylinders	13 x 20 ins.
" distance, c. to c.	4 ft. 8 "
Piston rod, diameter	2¾ "
Crosshead and guides	Single bar.
Valve gear	Stephenson; Meyer cut-off.
Inlet ports	1 x 12 ins.
Exhaust ports	1 x 12 "
Slide valves, lap, 1-16-in.; lead	⅛-in.
" " maximum travel	3 ins.
Air reservoir, Mannesmann tubes	Steel.
" number of tubes	27
" diameter of tubes (outside)	9 ins.
" " " " (inside)	8¼ "
" length of tubes	15 ft. 6 "
Reservoir pressure, with fresh charge	2,400 lbs.
" when requiring to be recharged	450 "
Cylinder pressure, initial	150 "

Street cars on the Hardie system have been in operation for some time on 125th St., New York city, as noted in our issue of Jan. 14, 1897. It may also be appropriate to note that a detailed description of the latest types of steam locomotives on the New York elevated railways was published in our issue of Feb. 15, 1894.

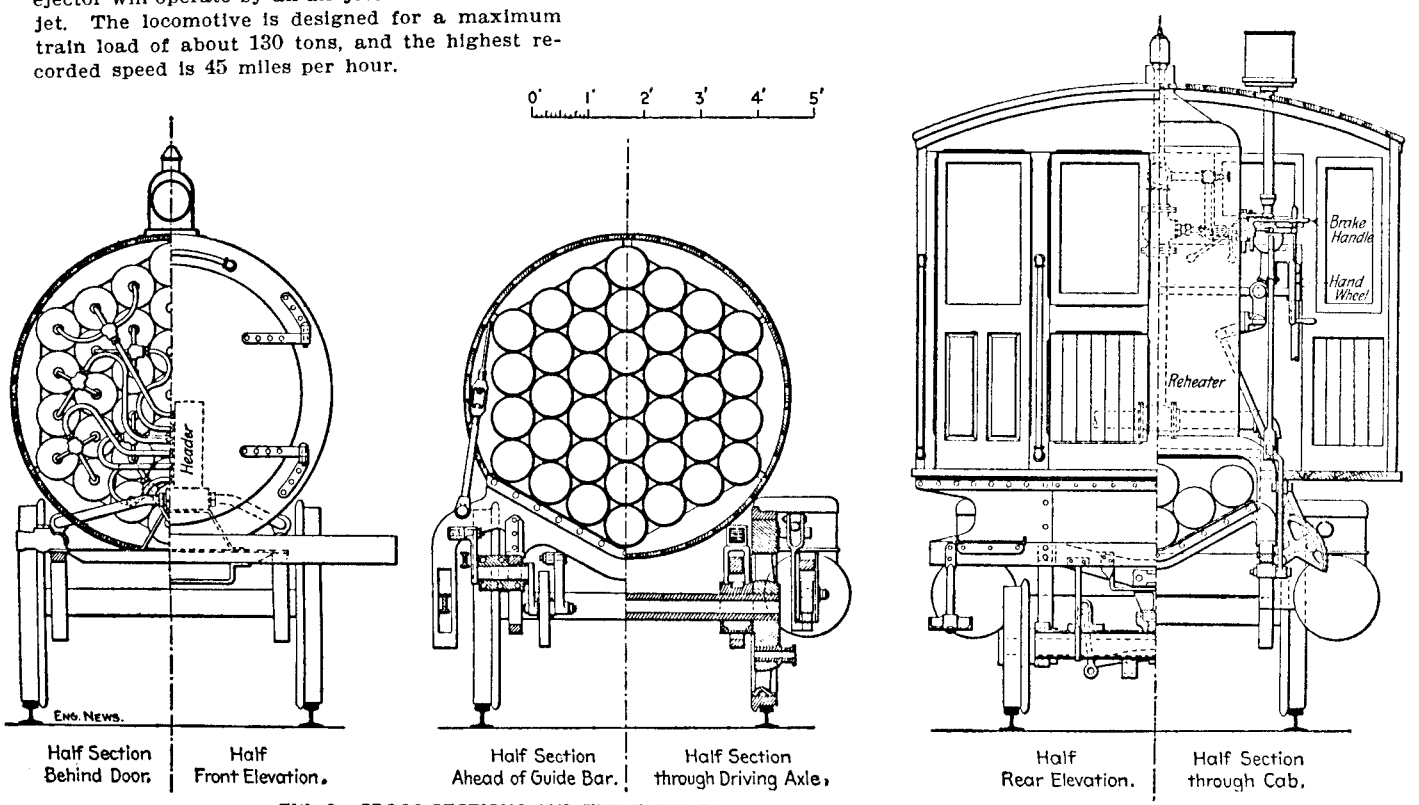


FIG. 2.—CROSS SECTIONS AND END ELEVATIONS OF COMPRESSED AIR LOCOMOTIVE.

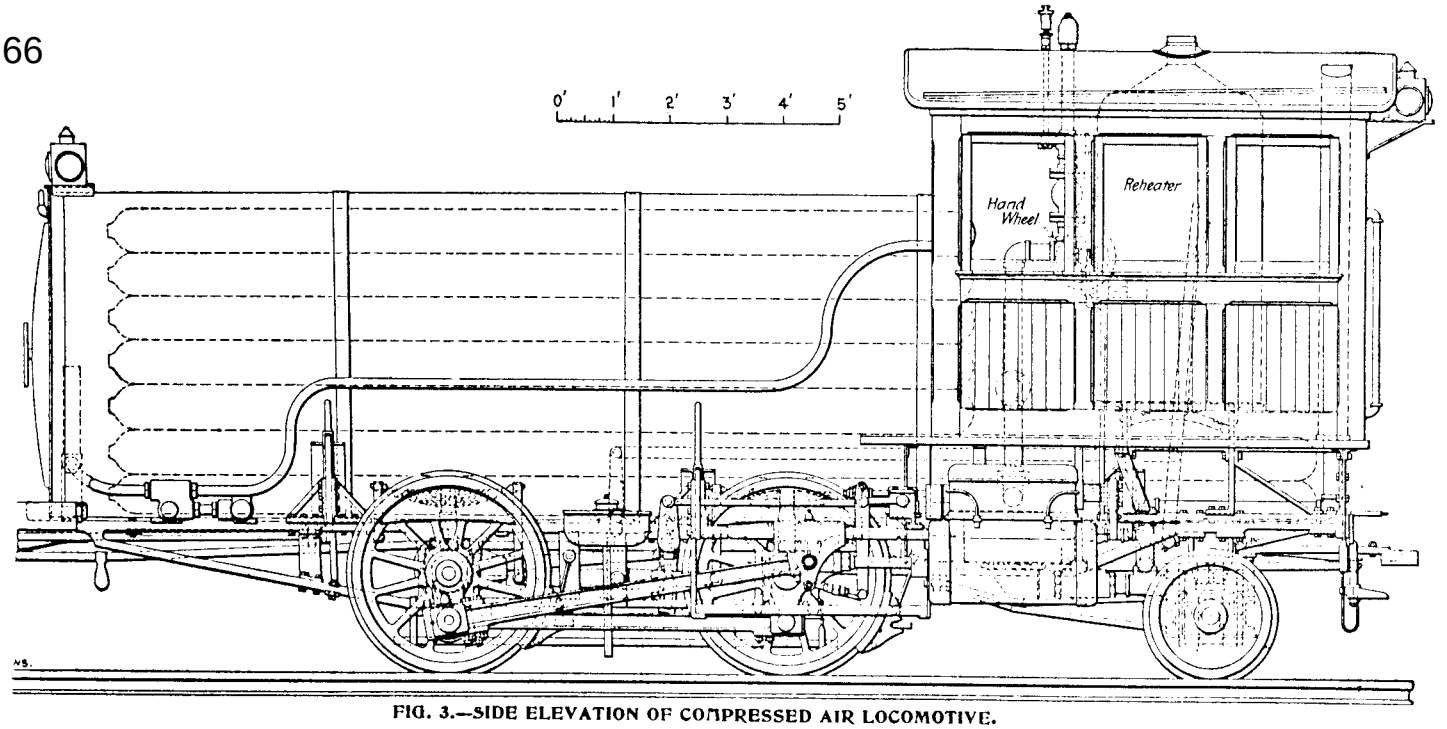


FIG. 3.—SIDE ELEVATION OF COMPRESSED AIR LOCOMOTIVE.

Compressed Air Motors.

In a review of the mechanical tramway systems of Europe by E. A. Ziffer, read before the International Street Railway Association at its last annual meeting at Stockholm, the statement was made that compressed air cars were then in use on seven lines in Europe, aggregating about 40 miles of track and that several other lines were in course of construction. The General Omnibus Company of Paris has had compressed air motors on three of its lines for a number of years and they are giving, according to the general manager of the company, excellent satisfaction. Many attempts have been made in this country to operate compressed air cars, but up to recently with exceedingly discouraging results. The value, however of a motive power for street railways that will obviate the well known objections to trolley lines, and the enormous expense and delay of equipment of conduit lines, has brought about within the last year a very rapid development of compressed air, as a motive power for this purpose.

Reference has previously been made to the motors of the Compressed Air Power Company which has installed a number of motors in New York City and has during the last month put some motors in operation on the Eckington & Soldiers' Home Railway in Washington, D. C. This company was formed a little more than a year ago by several prominent New York and Philadelphia capitalists headed by Wm. C. Whitney and Thomas Ryan, of New York, and Messrs. Elkins, Widener and Dolan, of Philadelphia. The engineers secured by this syndicate to develop this system were two young men of long experience in electric and cable railroading, J. H. Hoadley and Walter H. Knight. The latter has been chief railway engineer of the General Electric Company and one of the pioneers in electric railroading while the former is a prominent designer and builder of electric railways. These gentlemen approached the problem from an entirely novel standpoint, following rather the lines of the electric motor equipment than those of compressed air cars, as the latter had been built theretofore. They sought first a motor that would be like an electric motor—iron clad, and resting with one end upon an axle, to which its crank shaft was geared.

The unsatisfactory results attending the use of side rods and exposed machinery, in connection with the electric motor, were, of course, well known, and it was realized at once that in any form of air motor it was essential that the moving parts should be enclosed in a case where they could run in oil, free from dust, and where they would lubricate themselves continuously without the attention of the operator. It also seemed extremely desirable to continue the use of standard street car wheels, axles, trucks and car bodies, as these have all reached a standardized form which is known to insure the least expense of maintenance.

Owing also, to the limited intelligence of the motorman, and the necessity of more prompt control than is had

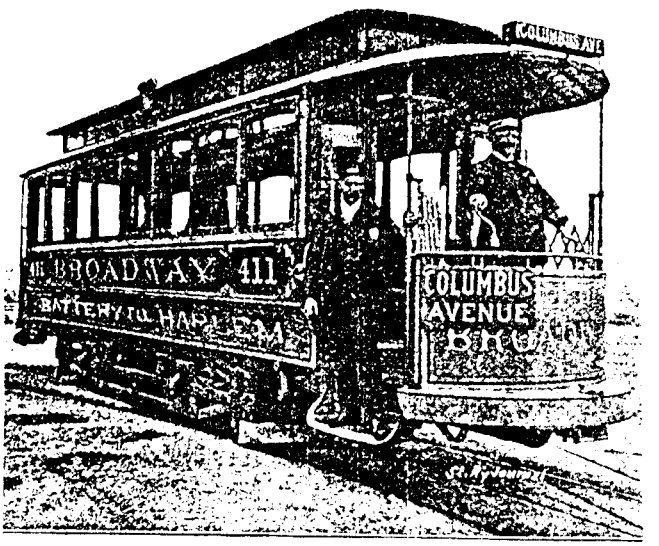


FIG. 1.—COMPRESSED AIR MOTOR CAR—NEW YORK.

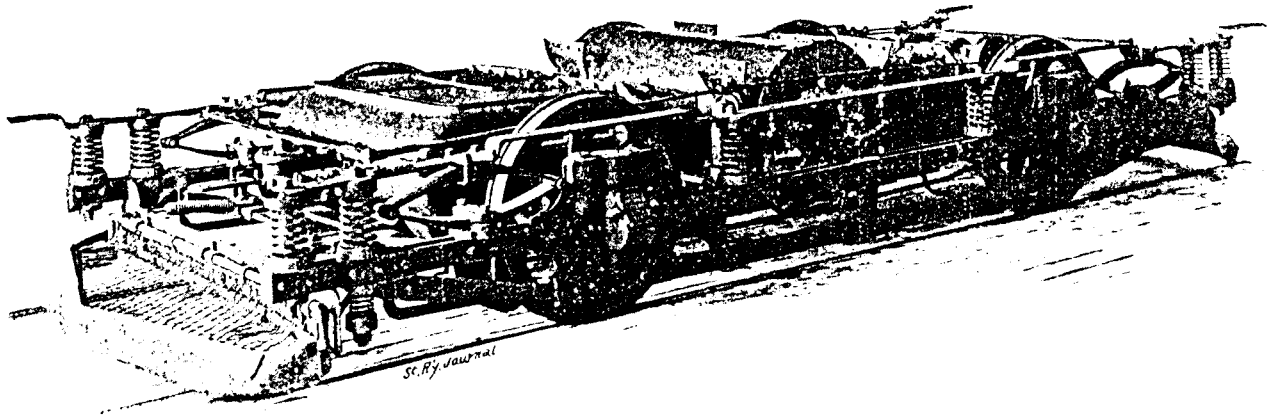


FIG. 2.—SIDE VIEW—COMPRESSED AIR MOTOR EQUIPMENT ON STANDARD BROADWAY TRUCK.

with steam locomotives, it was considered necessary to develop a controller, which could be operated by a single handle to perform all the various functions of the controller in their proper sequence without requiring thought on the part of the motormen. These three features of iron

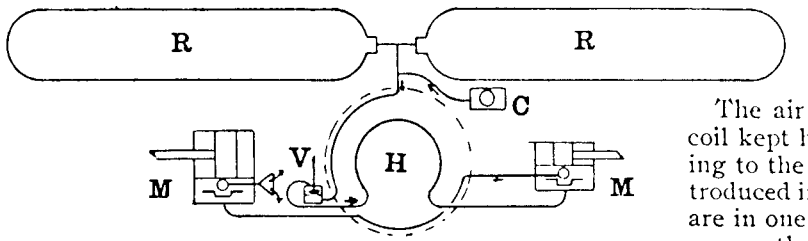


FIG. 3.—DIAGRAM SHOWING FLOW OF AIR

clad motors, running in oil, standard street railway rolling stock and single handle controller, were therefore made the distinctive features of the Hoadley-Knight system, which may be described more in detail as follows:

On each axle is mounted an iron clad motor, having two cylinders and cranks at right angles. One motor has two high pressure cylinders, 3½ ins. diameter and 6 ins. stroke, and the other motor has two low pressure cylinders, 7 ins. diameter and 6 ins. stroke. Upon the crank shaft is a pinion, about 9 ins. in diameter, meshing into a 23 in. gear wheel mounted on the middle of the axle; the axle is straight, as used for electric motors, and the wheels are ordinary street car wheels. The motor consists essentially of a cast iron case or basin, to which the two cylinders are bolted and in which all the moving parts, the piston rods, crossheads, connecting rods, cranks, gears, valve rods, eccentrics and reversing mechanism are located. The basin is covered with a lid which can be quickly removed, thereby exposing all the machinery for complete inspection. A sufficient quantity of oil is introduced into the basin to keep the moving parts continuously drenched with the lubricant, thus insuring for them the longest possible life, and reducing to a corresponding degree the maintenance account.

The air reservoirs, in the shape of seamless steel bottles, are under the seats of the car, and a pipe leads from them to a combined reducing and throttle valve, which reduces the storage pressure to the working pressure. The pipe before reaching the reducing valve passes around the heater, so that the air can receive sufficient heat to prevent freezing any moisture that may be in it.

The heater consists of a seamless flask charged with hot water under a pressure of from 150 lbs. to 250 lbs.

The air on leaving the reducing valve passes through a coil kept hot by the heater to a temperature corresponding to the steam pressure of the hot water, and is then introduced into the high pressure cylinders, both of which are in one motor on one axle. During its passage between the reducing valve and the high pressure cylinder means are provided for injecting a certain amount of moisture into the air, this having been found to give certain advantages as will be described later. In exhausting from the high pressure motor the air is again heated and passes through the low pressure motor on the other axle, from which it escapes through a muffler into the atmosphere. By having one motor high pressure and the other motor low pressure, undue slipping of the wheels is prevented, as when the high pressure wheels slip the low pressure motor gets more air and more

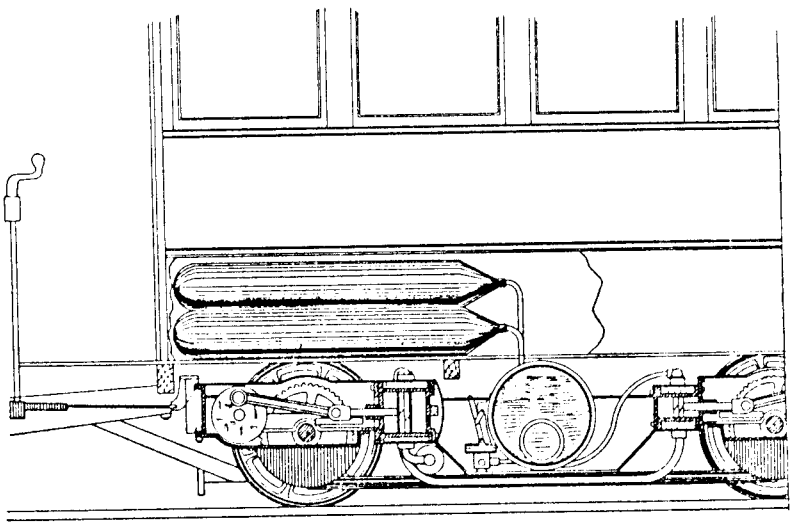


FIG. 4.—SECTIONAL VIEW OF MOTOR CAR.

pressure, and the back pressure from the receiver tends to stop the slipping. When the low pressure motor slips its wheels, it draws down the receiver pressure and thereby weakens itself, correspondingly increasing the strength of the non-slipping motor. The direction of the flow of the air is shown in Fig. 3 where *R R* are the air reservoirs, *V* the reducing valve, *H* the heater, *M M* the motors.

Twelve months' operation have demonstrated that these motors are highly efficient and exceedingly durable, all of the original parts being still in use. The manufacturers estimate that making a liberal allowance for the wear and tear that must occur and which, in the case of the more rapidly wearing parts, has been measured, the maintenance per car mile can be figured at not more than one cent, which compares favorably with that of the electric motor.

The weight of the standard Hoadley-Knight air car is tabulated as follows.

Car body	6,000 lbs.
Trucks	4,500 "
Air reservoirs	3,000 "
Heater	500 "
Motors (each 1500 lbs.)	3,000 "
Controlling apparatus	400 "
Piping	150 "
Total	17,500 "

The motors are capable of slipping the wheels on a dry rail under a weight of 30,000 lbs., and are therefore as powerful as the heaviest electric motor equipment. The total weight is little, if any, more than that of an equally powerful electric equipment, and the rigid weight on the axle, to which maintenance of track is mostly charged, is considerably less.

The air consumption of these cars varies from 30 lbs. to 40 lbs. per car mile, for a 34 ft. car of the Broadway type. About 11 lbs. of air can be compressed to 2000 lbs. per square inch per horse power hour. The cars require therefore, on an average a little over 3 h. p. hours per car mile, which in a modern compressor, running on a steady load and pumping into a reservoir of ample capacity, can be produced, it is claimed, for one-half cent per horse power hour, including all power house charges. To this must be added the cost of the hot water for reheating, which is given by the engineers of the system as one mill per car mile. The motive power expenses per car mile on this basis are therefore estimated as follows:

COST PER CAR MILE OF MOTIVE POWER.

3½ h. p. hours at ½ cent.	$.0175
Hot water for reheating	.001
Maintenance of motor equipment	.01
Total	$.0285

This compares favorably with the best that has been done with electric motors. The storage capacity for a run of 17 miles would be 45 cu. ft.

The Hoadley-Knight motors are controlled by varying the cut-off as well as by the throttle, the two being operated simultaneously. This method of controlling is adopted because it not only gives the highest efficiency, but also gives the greatest range of power. A car can be started with a promptness only limited by the friction of the wheels on the rails, or may be started with almost imperceptile acceleration. In common with other air cars, the start is easy and free from jerks.

A forward movement of the single controller handle starts the car and the propelling force is proportional to the distance that the handle is moved from its starting peint, so that any degree of acceleration can be obtained. A backward movement to the starting position brings the valve to a minimum cut-off and closes the throttle. A still further backward movement reverses the motors and opens

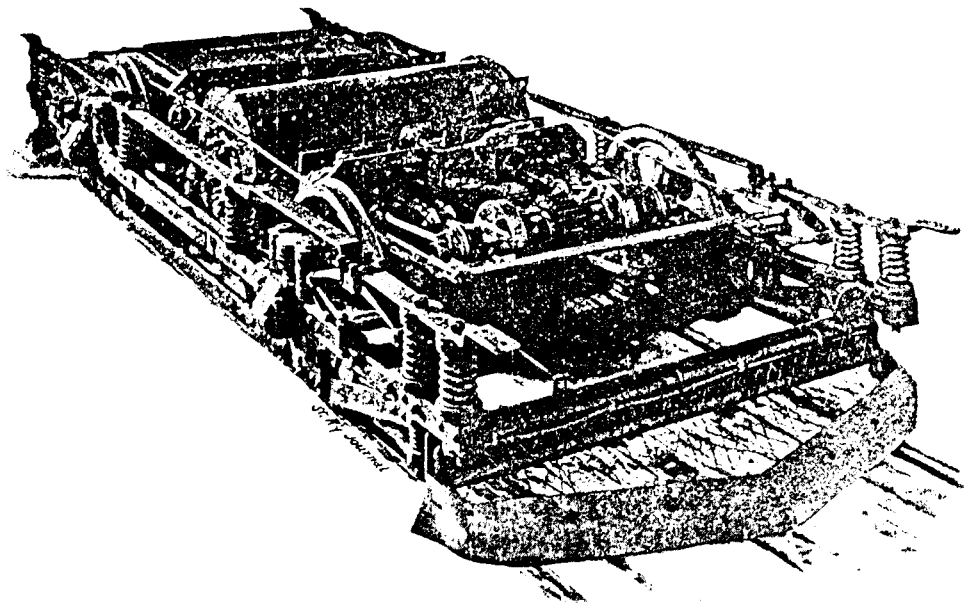
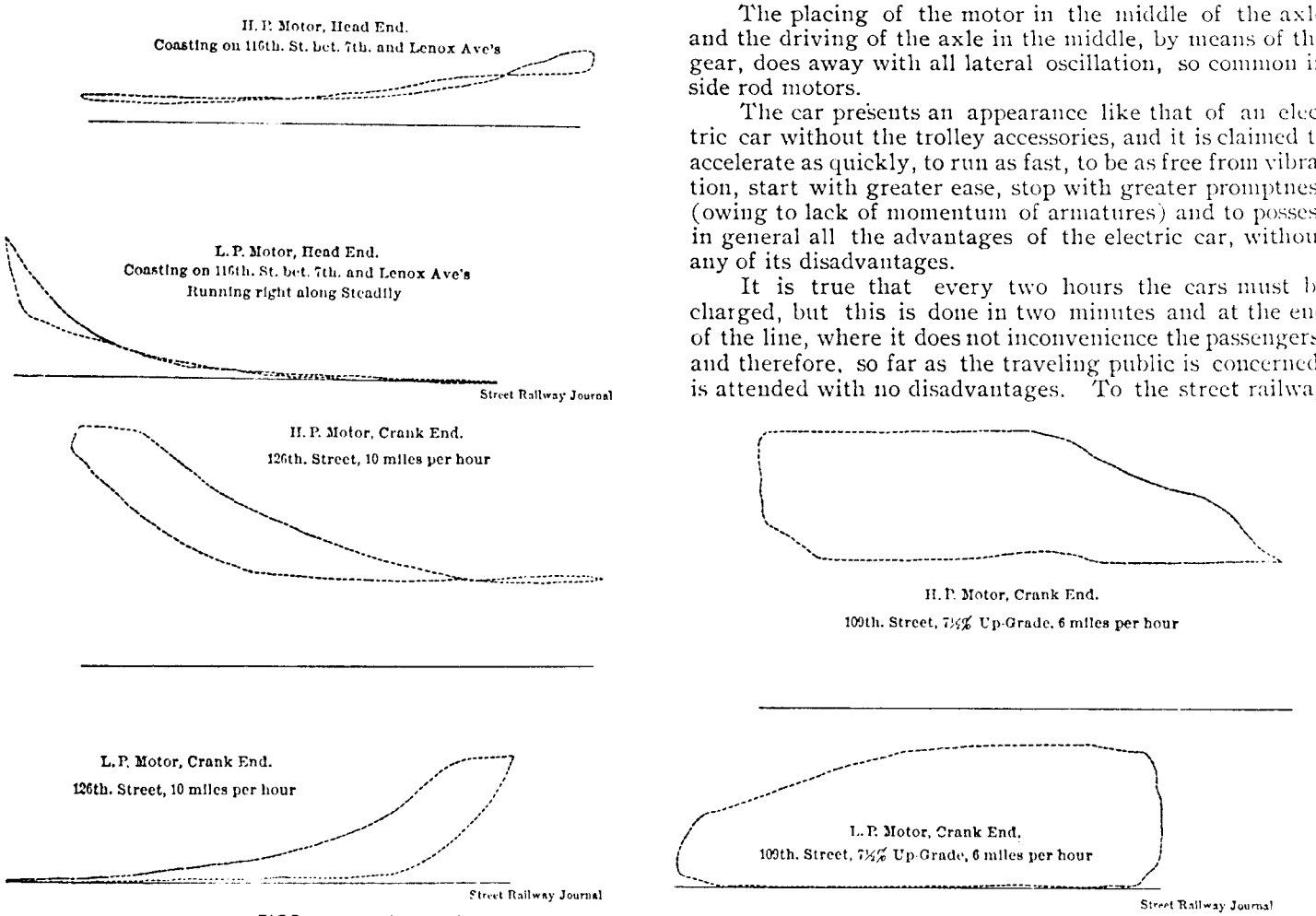


FIG 5—TOP VIEW—COMPRESSED AIR MOTOR TRUCK.

the throttle to back the car. The inventors claim that anything less simple than this is not feasible, or indeed safe for street car work, and they point out as sustaining this view, that the only successful electric controllers have been substantially as simple. Of course, with an electric motor the reversing handle has been kept separate, as it is undesirable to reverse an electric motor, but with an air motor there is no objection to reversing, and there is therefore no need of more than one handle on this account.

The inventors have made a large and exhaustive series of experiments on the subject of the heater. They have tried all the known forms. Their first experiment with the Mékarski heater, which is the one generally in use on air cars and in which the air is made to pass up through hot water, proved to them that such a method is liable to bring excessive quantities of water over into the motors, when heavy demands are made upon the air. They also found, what had not been generally recognized until they announced it, that such a heater, when the contained water is under a pressure exceeding that of the air, runs the motor, practically as a steam engine, with too much visible exhaust and too little air, and that after the pressure of the water in the heater falls below that of the air, practically no steam is generated, and the air enters the motor practically dry. Their experiments with dry heaters showed them that the same economy could be obtained with dry heat as with wet, but the heater itself proved objectionable and difficult to regulate. This brought about a return to the hot water heater, but with certain precautions against admitting the air to the water, which proved highly satisfactory.

Their experiments with air reservoirs have been probably the most extensive ever made. They have tried large numbers of each of the five different prominent


H. P. Motor, Head End.
Coasting on 116th. St. bet. 7th. and Lenox Ave's
L. P. Motor, Head End.
Coasting on 116th. St. bet. 7th. and Lenox Ave's
Running right along Steadily
Street Railway Journal
H. P. Motor, Crank End.
126th. Street, 10 miles per hour
H. P. Motor, Crank End.
109th. Street, 7½% Up-Grade, 6 miles per hour
L. P. Motor, Crank End.
126th. Street, 10 miles per hour
L. P. Motor, Crank End.
109th. Street, 7½% Up-Grade, 6 miles per hour
Street Railway Journal

FIGS. 6, 7 AND 8—TYPICAL H. P. AND L. P. MOTOR INDICATOR DIAGRAMS.

manufacturers and have experimentally blown up all kinds repeatedly, both with air and water, and find that they are all very much alike, both as regards strength and character of rupture. They are now using the Ehrhardt flasks. It seems to be generally admitted that the air motor would have reached a practical state of perfection much earlier, had it not been for the slow development of the art of making high pressure flasks, which until the last few years were not obtainable of sufficient strength to give the desired capacity within a reasonable space.

One of these cars will run 15 miles on a good track on a charge that is restricted to a space under the seats, and this could be even increased to 20 miles by crowding in all the flasks that the space could allow.

As the air pressure in the reservoirs is always limited to that which the compressor can give, and as the reservoirs themselves are capable of withstanding nearly three times this pressure, it will be readily seen that the element of danger is practically eliminated. There is no possible way in which the air pressure can be increased to the bursting pressure of the flasks. Furthermore they are protected by a safety pop set to open at a pressure slightly above that given by the compressor. There is no deteriorating influence incidental to their use. There has never been an explosion with any of these flasks by air, except when premeditated, and only then with the greatest difficulty and with apparatus especially constructed at great expense to bring the required force into play. Every flask is tested to 2½ times its working pressure before being used. Steam boilers are only tested 1½ times the working pressure.

The placing of the motor in the middle of the axle and the driving of the axle in the middle, by means of the gear, does away with all lateral oscillation, so common in side rod motors.

The car presents an appearance like that of an electric car without the trolley accessories, and it is claimed to accelerate as quickly, to run as fast, to be as free from vibration, start with greater ease, stop with greater promptness (owing to lack of momentum of armatures) and to possess in general all the advantages of the electric car, without any of its disadvantages.

It is true that every two hours the cars must be charged, but this is done in two minutes and at the end of the line, where it does not inconvenience the passengers, and therefore, so far as the traveling public is concerned, is attended with no disadvantages. To the street railway man it means practically almost no additional expense, as in general a wait of at least two minutes is made at the end of the line.

As compared with the storage battery car, which in its absence from dependence upon a distributing system the air motor resembles, the latter is claimed to possess the following advantages:

1. Its storage cells cost very little, comparatively.
2. They are a permanent investment, requiring practically no repairing.
3. The reservoirs can be charged in two minutes instead of six hours.
4. An exhaustion of the battery does not injure it (as with the sulphating of the electric battery).
5. The weight is about one-half.
6. There is no odor.
7. There is no corrosive liquid to slop over, or injure operatives' hands.
8. In case of necessity it can be charged along the line without leaving the line.

Barring fuel burning motors, which seem to be by common consent ruled out of the sphere of street service, compressed air stands alone as the only available stored force, which suffers no loss or deterioration while stored, which is instantly available, which requires no skill to utilize it and which is absolutely free from any offensive products. It is due to these practical features that compressed air has been so successful as a transmitter of force in mining work and air brakes, and the same advantages, it is believed by its promoters, will bring about its very general adoption for propeling vehicles.

The compressor problem for the high pressures used in this system is one which has required an especial amount of investigation.

It was found that the three stage compressors were unsatisfactory. For one thing, the temperature conditions required at least four stages to prevent the carbonization of the lubricant, and a four stage, belt driven compressor was constructed in demonstration of this and other points and was used afterward to run cars in Washington, D. C. With this compressor, a new system of compressor valves was worked out, with a view of saving the frequent renewals caused by such valves as were previously used. With the new style of valves this compressor has shown a capability of being run continuously night and day at full speed for six months, without requiring any renewals. The valves are of such simple construction as to cost almost nothing for renewal. With a four stage compressor there is not only the improvement due to better treatment of the lubricants, by reason of the lower temperatures, but also less back leakage, and greater economy to the extent of about 10 per cent, or more, as compared with a three stage compressor having the same elements of improved detail. As compared with any three stage compressor the market has heretofore offered, the saving is claimed to be much greater.

Taking advantage of the experience gained from the experimental four stage compressor, E. K. Hill, engineer of the American Wheelock Engine Company, designed a line of large compressors of a novel type, from which the builders claim to be able to produce most satisfactory results in extreme high pressure work as regards economy and durability. This type is shown by the accompanying side elevation which will give a general idea of the machine.

The steam end is a vertical engine of ordinary kind in general, but specially adapted to have connected upon each side of the column, the horizontal air compressing ends each of which has two stages arranged in tandem form. The steam end drives a center crank with shaft resting in bearings on each side. The crank shaft has a triple construction, i. e., there are three crank pins, one being driven from the steam end while the others serve to drive the compressor ends. These pins cannot, of course, be in the same vertical plane, but they are large in diameter and correspondingly short, so that in effect the center lines of the steam and air ends are in the same plane. Furthermore the steam and air cranks are of different lengths, the stroke thus differing, the steam end having a longer stroke. By this construction the proper relation between the piston speeds of steam and air ends is secured.

By this general arrangement of steam and air elements in the machine, the relation of power applied to resistance offered is extremely favorable to a uniform turning effect, so that a relatively small flywheel suffices to give the necessary regulation. The forces exerted oppose and balance to a degree that renders the total friction of the machine very small.

The arrangement and means of driving the air compressing cylinders is clearly shown in the illustration. This design gives directness and rigidity in highest degree. The air cylinders are mounted within and supported upon beds or housings which constitute water tanks for jacketing the cylinders and intercoolers, the latter consisting of tubes placed in the lower part of the housings. The cylinders are jacketed over the entire barrel and head, and an intercooler is provided between each cylinder as well as one for the final delivery. When consideration is given

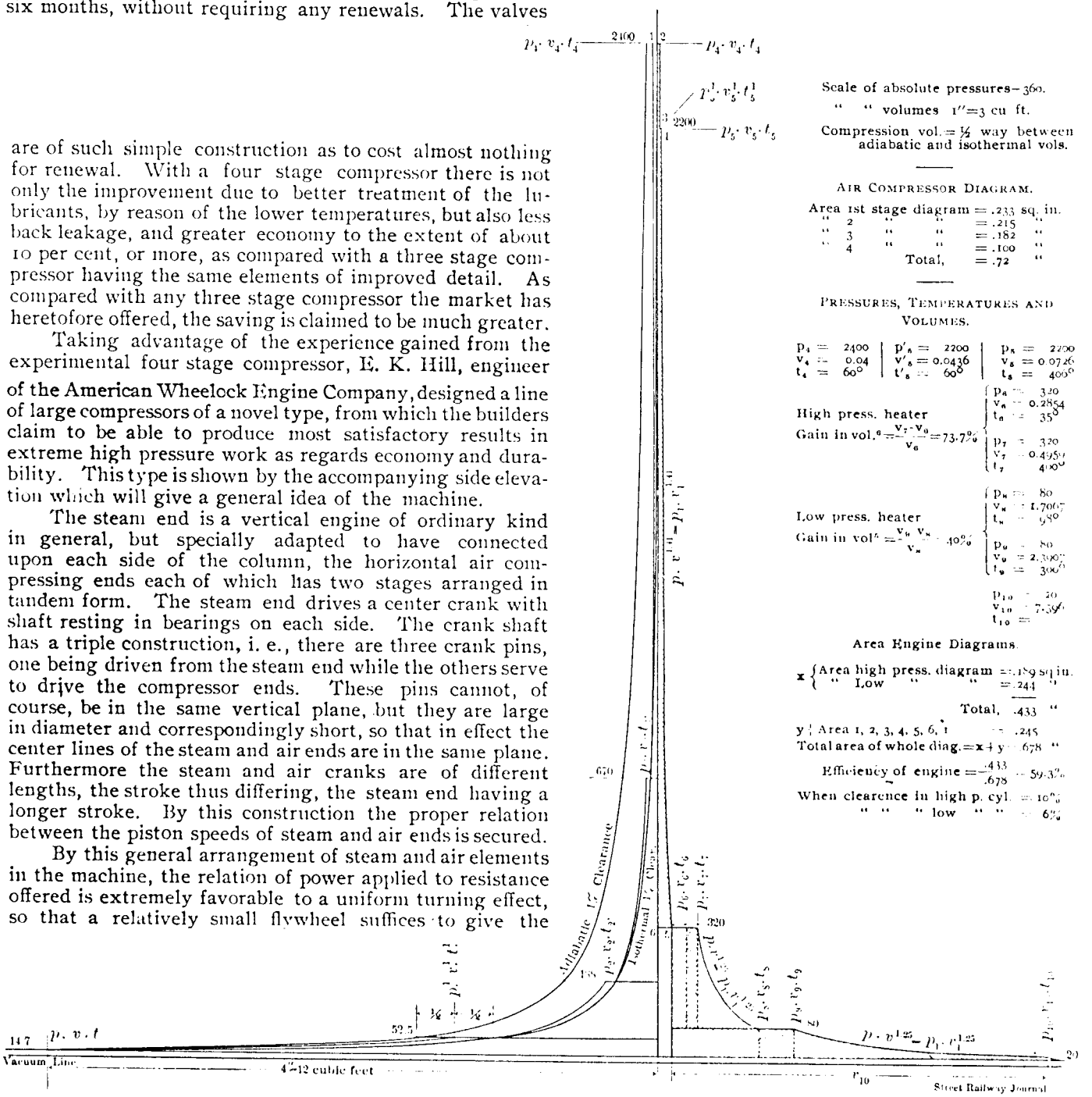

Scale of absolute pressures—360.
" " volumes 1"=3 cu ft.
Compression vol.=½ way between adiabatic and isothermal vols.
AIR COMPRESSOR DIAGRAM.
Area 1st stage diagram = .233 sq. in.
" 2 " " = .215 "
" 3 " " = .182 "
" 4 " " = .100 "
Total, = .72 "
PRESSURES, TEMPERATURES AND VOLUMES.
p_4 = 2400 v_4 = 0.04 t_4 = 60°
p'_5 = 2200 v'_5 = 0.0436 t'_5 = 60°
p_5 = 2200 v_5 = 0.0746 t_5 = 400°
High press. heater
p_6 = 320 v_6 = 0.2864 t_6 = 35°
Gain in vol.% = 73.7%
p_7 = 320 v_7 = 0.4959 t_7 = 400°
Low press. heater
p_8 = 80 v_8 = 1.7007 t_8 = 98°
Gain in vol.% = 40%
p_9 = 80 v_9 = 2.3907 t_9 = 300°
p_{10} = 20 v_{10} = 7.396 t_{10} =
Area Engine Diagrams.
x Area high press. diagram = .189 sq. in.
" Low " " = .244 "
Total, .433 "
y Area 1, 2, 3, 4, 5, 6, 7 = .245
Total area of whole diag. = x + y = .678 "
Efficiency of engine = .433/.678 = 59.3%
When clearance in high p. cyl. = 10%
" " " low " " = 6%
Adiabatic 1% Clearance
Isothermal 1% Clearance
Vacuum Line
4½-12 cubic feet
Street Railway Journal

FIG. 9.—POWER DIAGRAM OF AIR COMPRESSION AND EXPANSION.

to all the pipe connections and other details necessary for the air and water in four stages, it will be evident that this design is singularly compact and direct.

The cylinders are all single acting and fitted with special care to secure tightness of pistons. The air valves are made upon a novel system the result of extensive experimenting. All usual forms of valve that were tried were found inadequate to answer the severe requirements of endurance and tightness under heavy pressures. The valves are conveniently accessible without disconnecting any main part of machine, and can be replaced in a few minutes.

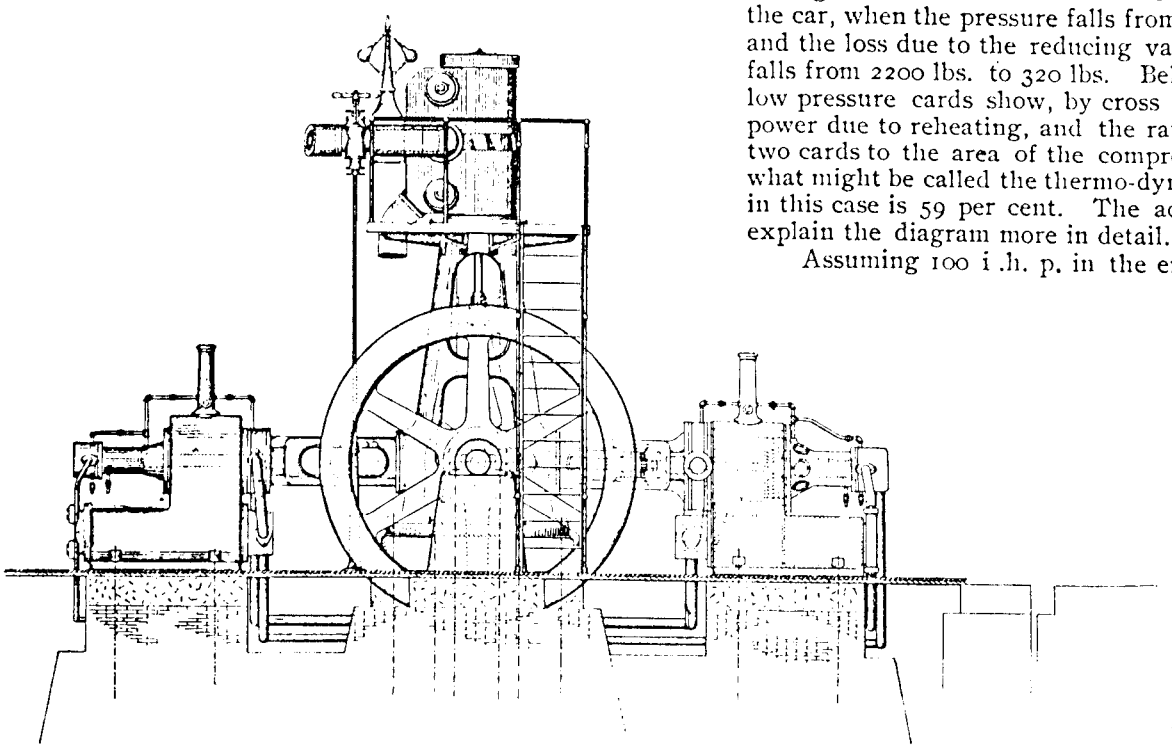


FIG. 10.—FOUR STAGE AIR COMPRESSOR.

The machine as shown has a single steam cylinder, and has the outboard end of shaft carried in a bearing. The design is such, however, that the shaft of a duplicate machine can be connected, thus forming a duplex compressor with a single flywheel between, and using compound steam cylinders, or the single machine can be fitted with vertical, tandem, compound cylinders.

The steam end is supplied with a high grade automatic cut-off valve gear, and all the details have been worked out with great care, the special features having been developed by exhaustive experimental use. It would seem that the claims of the builders that they have a unique and extremely efficient compressor in an entirely new class of machines, is well founded.

The power diagram shown in Fig. 9 illustrates in a graphic manner the effect upon the air during the four stage compression, and the subsequent two stage expansion; the left hand half of the diagram showing compression, and the right hand expansion. The compression side shows how closely the four stage compression approximates the isothermal. The adiabatic curve from atmosphere to 2400 lbs., also is shown, to give a graphic idea of the saving in power effected by the use of four stages. On the right the curve illustrates the loss, due to charging the car, when the pressure falls from 2400 lbs. to 2200 lbs , and the loss due to the reducing valve, when the pressure falls from 2200 lbs. to 320 lbs. Below this the high and low pressure cards show, by cross hatching, the gain in power due to reheating, and the ratio of the area of these two cards to the area of the compression cards, gives us what might be called the thermo-dynamic efficiency, which in this case is 59 per cent. The accompanying data will explain the diagram more in detail.

Assuming 100 i .h. p. in the engine during the compression, there is found to be a loss of 20 per cent in the friction of the engine and compressor. Of 80 h. p. thus exerted in compressing the air, 40 per cent is lost in the subsequent reduction of the pressure. Of the 48 h. p. developed in the motor cylinders, there is a further loss by leakage of about 10 per cent and the friction of the motor brings the residual power delivered to the axle down to 35. This comparatively low efficiency is largely offset by the fact that the compressor runs on a practically constant load, and at a correspondingly high efficiency.

The expense of installing this system does not differ materially from that of the electric trolley system. The compressed air power plant can be installed for the same amount as an electric power plant, and the cars, while costing somewhat more than the trolley cars, are more than offset, it is claimed, by the expense of the trolley line itself. As compared with the underground trolley, there is of course, a saving of the interest and maintenance of the conduit, a sum which would in itself exceed in many cases the whole motive power expense of the compressed air car.

THE HARDIE COMPOUND AIR LOCOMOTIVE, described and illustrated in our issue of June 24, 1897, and built by the American Air Power Co., made an exhibition run on the Sixth Avenue line of the Manhattan Elevated Railway on Aug. 19. The regular run from Rector St. to 58th St. was made in 19 minutes, with a train laod of 192 invited guests. It is said that the motor may be put into regular service shortly, to test the actual economy of the system. The trial run was successful in proving the ability of the motor to do the work required.

August 26, 1897.

ENGINEERING NEWS
AND
AMERICAN RAILWAY JOURNAL.

Vol. XXXVIII., No. 9.

Trial of a Compressed Air Locomotive on the Manhattan Elevated Railroad.

The Hardie compressed air motor, which was built by the American Air Power Company to demonstrate the possibility of drawing trains on the Manhattan Elevated Railroad, was put into service Aug. 23, and a public test of it was made by taking a train loaded with 192 persons over the Sixth Avenue road from Rector Street to Fifty-eighth Street and back to Cortlandt Street.

Robert Hardie drove the locomotive and H. Paige, a regular engineer, was his pilot. Among those on the train were W. J. Fransioli, general manager of the elevated roads; E. J. Elias, president of the Third Avenue Railroad Company; H. H. Vreeland, president of the Metropolitan Street Railway Company; F. S. Pearson, chief engineer of the Metropolitan Street Railway Company; David Young, general manager of the Consolidated Traction Company, of New Jersey, and a number of steam railroad men.

The run to Fifty-eighth Street was made without a stop, in nineteen minutes. There had been no attempt to make special speed on the run because there was a regular train ahead, but it was made in three minutes less than the regular schedule time. The trip back was begun at 10:01 o'clock and completed at 10:27.

A number of the passengers then visited the plant at 100 Greenwich Street, where the air is compressed for the use of the locomotive. A big steam engine operates two compressors, each of which consists of two water jacketed pumps. The first pump receives the air and squeezes it down to about 65 lbs. pressure to the inch, the next one reduces it to about 165 lbs., the third to about 750 lbs., and the last to nearly 3000 lbs. Water circulates about each cylinder to carry off the heat and the passage of the air is from one cylinder to another through a coil of submerged pipe for the same purpose.

The air is finally forced into a stack of steel tubes, which are arranged in four sets. From these it passes in a pipe to the water station on the elevated road near Rector Street. When the engine is to be charged a connection is made with this pipe and the air passes into another stack of steel tubes concealed in the boiler like jacket, which receive it at a pressure of 2500 lbs. to the inch. A charge which will run a train to Fifty-eighth Street and back can be taken on in the same time it usually takes to receive the water for a trip.

When the air is being used it passes out through cylinders exactly like those for steam, except that special valves are used to control it. Between the tubes which hold the charge and these cylinders are the peculiar features of the Hardie system. A reducing valve delivers the highly compressed air into a receiving tank in the cab at a much lower pressure, and then it passes through a tank of hot water, which returns to the air some of the heat which it lost in being compressed, and also gives back to it the water vapor which it also lost in that operation. It is this feature which, Mr. Hardie claims, makes his motor commercially economical in working.

It is intended that the motor shall be placed in regular service upon the road to test the actual economy of its operation, but no announcement has been made as to when this will be done.

REPORTS OF EXPERIENCE WITH COMPRESSED AIR MOTORS ON ELEVATED AND STREET RAILWAYS.

We are able to present to our readers this week several interesting papers bearing on the much disputed question as to the economical results obtained with compressed air motors on street railways. The first of these is a statement furnished to us by General Hermann Haupt, Consulting Engineer of the American Air Power Co., and the others are reports made to the Commissioners of the District of Columbia by engineers employed by them to report upon the system of traction which should be adopted upon the street railway lines of Washington. As our readers may recall, the street railway lines in Washington, like those on Manhattan Island, are unable to secure the assent of the local authorities to the use of the overhead trolley system. They are, therefore, practically compelled to choose between compressed air motors and an underground electric system, and their choice must be approved by the District Commissioners. The Eckington & Soldiers' Home and Belt Line railways, of Washington, have applied to the Commissioners for permission to adopt compressed air motors, and the Commissioners, before granting their approval, desire to satisfy themselves that this system will give a safe and reliable service, and that its economy is such as to enable the companies to conduct their business at a fair profit. It is recognized that the city has an interest in having its street railways operated by a responsible and solvent corporation, and that anything which might tend to delay the return to solvency of the companies whose application is under consideration would be objectionable.

We are indebted to the courtesy of Capt. W. M. Black, Engineer Commissioner of the District of Columbia, for the official reports which are here presented:

Statement by Gen. Hermann Haupt.

To the Editor of the Engineering News.

Sir: Requests have been sent to the writer for information in regard to the exact results of the tests made on the Manhattan Elevated Ry. with the compressed air motor.

As these tests have developed the possibility of some improvements in details, it was not considered expedient to publish statements that might give erroneous impressions in regard to the full efficiency of the system. The steam locomotive of the present day is the result of more than half a century of development and improvement, and it would have been most unreasonable to expect that the air motor for elevated roads, involving the use of so many new inventions and novel mechanical expedients, should in its early trials be found so perfect in all its details that no improvement could be found possible. Such a result would have been unprecedented in a mechanical construction of this character, but as reports have been circulated that the motor failed to fulfil requirements in a test to which it was subjected, it seems to be desirable that the facts should be given. So far from failure, the test demonstrated a most gratifying success for the system itself, but indicated the necessity of some slight changes in the details, the two most essential being an increase in the diameter of a ¼-in. pipe leading to the motor cylinders, and the other, a change in the valve, which was found to be overbalanced, in consequence of which it lifted under pressure and allowed a considerable waste of air.

To give your readers an intelligible presentation of the subject, it is necessary to give a brief history of the Hardie motor of 1881: This motor was constructed at the Baldwin Locomotive Works in Philadelphia and was placed on the track of the Second Ave. Elevated R. R. at Harlem. The reservoirs were of riveted boiler iron, capable of sustaining a pressure of 600 lbs. per sq. in., and the reservoir capacity was 460 cu. ft. The motor cylinders were 12½ × 18 ins. The driving wheels were 42 ins. in diameter. The weight at the shop was 39,350 lbs., which was subsequently increased 2,500 lbs., making the total weight on the track 41,850 lbs. The pressure at starting at Harlem was 600 lbs.; at finish at South Ferry, 195 lbs.; consumption, 12,675 cu. ft. of free air, equivalent to 1,491 cu. ft. per mile, the distance run being 8½ miles.

The train consisted of four cars, and the total weight of the train was 81 tons. The train ran from Harlem to South Ferry in exact schedule time, making all the stops. There were present the Chief Engineer, Master Mechanic, and most of the officers of the road. The Engineer was taken from one of the regular steam locomotives. The test was a perfect success, and written certificates were given by all the officers present. Col. Hain, it is said, declined to give a certificate to Mr. Hardie in regard to the test, as he did not wish at that time to excite the public by any publication of the facts.

One of the strongest certificates was given by the engineer who ran the motor. He was delighted with its performance and declared that he had neither water nor fire to look after, and his view of the track was unobstructed by steam or smoke. There was sufficient reserve of air after the trip to run the motor light back to the engine house. Notwithstanding this successful test, the company was not ready to adopt compressed air and make a radical change in the equipment.

Mr. Hardie was soon after appointed Superintendent of the Rome Locomotive Works, and the writer, General Manager of the Northern Pacific R. R. The world was not yet ready for compressed air and no further efforts were made until 1892, when they were resumed, and the motors that have so successfully operated for a year on 125th St. are in part the result of these efforts.

In designing the motor for the elevated railroad of 1897, the results of former tests furnished the only available data from which to proportion the parts. The conditions presented were onerous in the extreme. The weight of the motor was limited to 47,000 lbs. and the weight of the train increased from 81 to 130 tons.

If the consumption of air be assumed as in proportion to the weight of the train, the required amount of air per mile, based on the results of 1881, would be 2,393 cu. ft. for a train of 130 tons; but a more accurate mode of estimating the volume of air would be to assume that it should be in proportion to the resistance to traction of the train, the motor requiring more power in proportion to weight than the cars. Assuming the resistance of the motor to be 40 lbs. per ton, for a weight of 23½ tons, and the car resistance 10 lbs. per ton for a weight of 105½ tons, the train of 1881 required 1,440 lbs. average traction and the train of 1897 would require 2,065 lbs. traction and 2,140 cu. ft. of air per mile, which, to allow a margin of safety, was assumed to be 2,400 cu. ft.

During the night of Sept. 1 the air motor was subjected to a very severe test in competition with a steam locomotive of somewhat heavier weight, which had been put in thorough repair. A train was made up of five cars and extra load was put upon the cars to represent 100 passengers per car. The seating capacity is only 48. The train was hauled successively each way by the steam motor and the air motor, stopping a prescribed length of time at each station. It was reported by an expert from Stevens Institute who was present that the steam motor, said to be 2,000 lbs. heavier, was taxed to its utmost capacity, that it did not reduce its speed to six miles per hour, as prescribed on a curve, and that it thereby acquired momentum to aid in ascending a grade at the end, also that the fires were urged to the highest degree possible, a stream of sparks flying from the stack; notwithstanding these efforts the steam motor could not make schedule time.

The air motor stood the test without sticking fast. Its speed was kept down to the prescribed 6 miles per hour upon the curves. It lost more time than the steam motor during the entire run, being 8¼ minutes behind schedule time in going up and 6 1-10 minutes in returning and the consumption of air was largely in excess of the 2,400 cu. ft. estimated.

In discussing this result with Mr. Hardie, it appeared that the failure to make schedule time was due to insufficient diameter of the air pipe leading to the cylinder. In the motors operated on 125th St. the acceleration was as quick as could be desired, and, based on this experience, it was supposed that a ½-in. pipe for the elevated motor would be sufficient. It proved, however, to be not quite large enough. Of course it will be a very simple matter to substitute a larger pipe, and it should need no demonstration to convince any person of ordinary intelligence that the acceleration of an air motor can be much quicker than with a motor operated by steam. The pressure upon the piston of a steam motor is limited by the pressure of steam in the boiler, while in the Hardie motor the pressure can be instantly increased to 200 lbs. or more, if desired. The failure to make schedule time, therefore, does not indicate any defect in the system but only in a very simple detail which can be readily corrected.

As this motor had to be designed without a knowledge of the exact tests to which it would be subjected, or conditions to be fulfilled, it would have been a success beyond precedent if in these first trials no defects had been perceptible and no improvements found possible. So far from failure, the tests should be considered as demonstrating the complete success of compressed air as a system, for the defects are easily remedied.

Although the capacity for storage of the motor is limited to about 9 or 10 miles with a maximum train, the air system allows an indefinite extension by placing reservoirs under the passenger cars.

The officers and directors of the Manhattan R. R. exhibit a commendable prudence in requiring actual demonstration before any change of system will be authorized. If steam is to be superseded the choice must be between compressed air and electricity, and the proper test would be to require estimates for a full installation of such a line as the Third Ave. with maximum trains of 130 tons at intervals of 1 minute, and a guarantee from responsible parties that the line shall be installed and operated within the estimated limits of cost.

The third rail system appears to give satisfactory results on one of the suburban lines of the New Haven Railroad, but its capacity is limited and the limit of its capacity on that road has been nearly reached. It would require many rails to transmit the current that would be required for the Third Avenue elevated R. R.

With independent motors, either steam or air, the results obtained from one motor can be depended upon for a thousand, and no outside construction, as in electricity, must be established and maintained with the constant menace to life, when, for economy in the weight of copper very high voltages are employed.

Comparative Estimates of Cost.

The data are not available for a full detailed estimate of the cost of plants and operation of the elevated roads of New York with steam, compressed air, and electricity, but they are sufficient to indicate a decided economy in the use of compressed air.

From the annual reports of the Manhattan Ry. Co., it is found that the number of locomotives is 335; the train miles per annum, 9,170,940; the cost of fuel, $900,022; repairs, $202,947; and the costs per train mile are: fuel, 9.8 cts.; repairs, 2 cts.; water, 1.17 cts.

The cost of compressed air is given in the published statements of the American Air Power Co. as 3 cts. per 1,000 cu. ft. of free air compressed to 2,000 lbs. per sq. in., including maintenance, labor, fuel, and interest on cost of compressor station.

The average quantity of air consumed per train mile has been stated to be in proportion to the resistance to be overcome; a light train requiring less than a heavy one. It has been shown on the basis of the tests of 1881 that with an air motor in efficient condition the consumption of air for a maximum train of five cars, on the Second Avenue road, or on one of equivalent resistance, should not exceed 2,400 cu. ft. per mile. This estimate allowed 100 passengers per car or 500 to the train, but as the maximum number was carried only during a short period, morning and evening, the average weight of trains must have been less, and it is the average and not the maximum that determines the volume and the cost of the air required for operation.

It is probable, therefore, that less than 2,000 ft. should be considered a full average, but to avoid any question, the maximum of 2,400 cu. ft. will be allowed for all the trains, which will give for fuel and expense of power station, 7.2 cts. per train mile, saving 2.6 cts. as compared with steam.

The repairs of locomotives cost 3.2 cts. per train mile, but as there are no boilers or fireboxes on air motors, the repairs of which constitute the chief expenses, at least a cent and a half should be saved. The saving in water for steam may be estimated at ¾ ct. per mile. The aggregate of these three items is 4.85 cts. per train mile, or on 9,275,000 miles = $449,837 per annum.

In a comparison with electricity the difference would be much greater in favor of compressed air. In an estimate made by the writer, some years ago, on the lines of the ordinary trolley installation, maximum transmission of currents five miles and 500 volts at motors, the cost of a full electrical installation for trains of 130 tons at the one minute headway was found to be nearly four times as great as the equivalent with compressed air. This estimate was submitted to electrical experts for revision. Conceding that economies have been secured by recent

improvements with excessively high voltage transmission, it is not and cannot be claimed that one-half the cost can be saved, and if it were, the electric plant would still cost twice as much as with compressed air.

As an illustration of the difference in cost of plant between compressed air and electricity in ordinary street car service, it may be stated that proposals having been invited for the equipment of the Eckington Road in Washington, D. C., the following proposals were submitted:

By American Air Power Co., compressed air.... $399,000
By Hoadley & Knight, compressed air.... 508,000
By General Electric Co., underground electric.. 1,795,105
By Westinghouse Co., underground electric.. .. 2,208,506

The air motors of the American Air Power Co., ran for a year on 125th St., to regular schedule, without the loss of a trip in all conditions of weather, and continued in full service when the cable and underground electric lines were blocked. The cost of plant and of operation with a full equipment of 364 cars was demonstrated from the daily records to have been less than with an overhead trolley (see reports in "Compressed Air" of March, 1897). The repairs of motors were covered by ¼ ct. per mile, notwithstanding the fact that no efforts were made to protect the motor machinery from dust.

With the data obtained from the operations on the 125th St. road, it is a very simple problem for any intelligent engineer to estimate the size of cylinders and the consumption of air on any other line to fulfil any required conditions and overcome any increased resistances; any grade within the power of a steam locomotive can be ascended with an air motor of equal weight. It is absurd to assume that the experimental stage has not been passed and that a year of trial must be demanded on every new road upon which it is proposed to introduce compressed air.

Herman Haupt.
Consulting Engineer General Compressed Air Co.

Report by Edward G. Emack.

To the Engineer Commissioner of the District of Columbia.

Sir: In compliance with your instructions with reference to the proposed adoption of the "Hoadley-Knight" System of Compressed Air Propulsion on the Eckington and Soldiers' Home and Belt Railways of this city, I beg leave to submit the following report:

(A description of the routes and grades of these railways is given, which we omit.—Ed.)

Weights of Motor Cars.

The weight of the air-motor car in use on the Eckington Railway is given by the officials of the company at 15,100 lbs., though Mr. McFarland states that he was informed by representatives of the Compressed Air Co. that the motor weighed about 20,000 lbs., and that it was billed by the railroad company at the time of shipment from New York city here as weighing 22,000 lbs.

The weight of the electric motor-cars on the Metropolitan R. R. of this city is estimated by the officials of that company from 15,000 to 16,000 lbs.

Since the spring of 1897 the officials of the above-named railways have been conducting experiments in compressed air propulsion under the above system, and claim to have obtained satisfactory results from the beginning.

During the past two months there has been received at the office of the Commissioners a number of protests from patrons and residents of the vicinities of said railways against the issuance of permits for their operation by compressed air as a motive power, citing as objections to such system its rejection in New York city after a thorough test, the disagreeable odor and heat from the fire-pot and stove-pipe passing through the car, the cloud of dust entering the car through the rear door and windows in dry weather, the oscillation and vibration of the car due to its great weight and working of machinery, the liability of the air-tubes or bottles to explode under the heavy pressure to which they are subjected, the noise of escaping air in starting and in ascending grades, and the inability of the car to make regular and uninterrupted trips over the various sections of the roads.

On or about June 10, 1897, the Superintendent of the Water Department, Mr. W. A. McFarland, was detailed by the Commissioners to inspect personally the construction and operation of the experimental cars in use on these lines, and to make a complete report thereon, which he submitted under date of June 24, 1897, supplemented by further reports on June 26 and 28, 1897. After giving a full description of the mechanism of the cars, Mr. McFarland states that "car No. 91" was on regular service between the power house at 4th and T streets, northeast, and 15th and G streets, northwest, making four round trips per day. The heaviest grade on this route being a short one of 5.25% at the upper end of Eckington Place; the next in importance being a long 3% grade on New York avenue. The length of this run and return is 5.4 miles and includes 16 curves.

On June 11 and 12 he reports four ordinary runs over this route (the motor-car being much impeded in its progress by the presence of horse-cars using the same tracks) in the average time of 46¼ minutes, a rate of about seven miles per hour, including stops averaging about one per minute. The car starting with an average pressure in the air bottles of 2,002½ lbs. per sq. in., and returning with an average reserve of 304½ lbs. per sq. in.

The compressed air is carried in seamless steel bottles under an initial pressure of from 2,000 to 2,300 lbs. per sq. in., gage pressure, and is fed through a reducing valve said to reduce the air pressure to about 200 lbs. per sq. in. on entering the high-pressure cylinders.

On the 12th instant the car was run over the Maryland and Washington track as far as the District line, where a probable speed of about 18 miles per hour was attained.

Car No. 400 arrived on June 16, and the first test run made on the 18th. On the 18th this car left the power-house with 2,225 lbs. gage pressure and made the trip to 15th and G streets, northwest, and return, with a fall in pressure to 250 lbs. On the third run the longitudinal brace under the motor struck a high place in the cobble pavement, at Florida Avenue and Eckington Place, and the car stuck fast, necessitating the use of a trolley car to free her.

On the 19th a run to Brookland and return was made; distance, 3 miles; maximum grade, 5%; fall in pressure, 750 lbs.

On the 21st a run was made from the power house to 7th and B streets, northwest, in 21 minutes. This run includes the most difficult grade (about 6%) on the whole system, on which are two sharp curves (viz.: on 6th Street and Louisiana Avenue, from C to 5th Street, northwest).

In ascending this grade on the return trip a failure to control the car occurred, the details of which are given in Mr. McFarland's report. It is proper to state in this connection, however, that Mr. McFarland, verbally, attributed this failure to the fact of the track at the head of the Louisiana Avenue grade being greasy prior to the test, and the car wheels becoming coated with grease in attempting to pass the curve slipped on the rails when the effort was made to descend for the purpose of securing greater headway.

Immediately after the above-named trouble the car went up the grade at a good speed and reached the power house with a reserve pressure of about 300 lbs.

On the 23d two trips were made, from Eckington to 15th and G streets, to Brookland, to Eckington, and from Eckington to Center Market, to Brookland, to Eckington, Starting with pressures of 2,300 and 2,250 lbs., running 8½ and 8 miles, and returning without incident, with pressures of 150 and 200 lbs., respectively. No passengers carried.

On the 25th this car, under full service conditions, carrying about 20 passengers, made the trip without difficulty from 4th and T streets, northeast, to Center Market, to Brookland, and return to 4th and T streets, making 37 full stops, including one in each direction on the heavy grade on Louisiana Avenue, between 5th and 6th streets. Starting with pressure of 2,050 lbs. and returning with 250 lbs. reserve, or sufficient for run of about three-quarters of a mile. Length of run, 8 miles.

On the 27th the same car successfully made the trip from 4th and T streets, northeast, to Center Market, to entrance to Catholic University, and return to 4th and T streets, carrying 46 passengers, in about 58 minutes; distance, about 7 miles. Pressure at starting, 2,000 lbs. Reserve at end of trip, 350 lbs., or sufficient for a run of about 1¼ miles. Made 34 full stops, including one at 6th and C streets, and again on Louisiana Avenue on the return trip, when restarting was done without difficulty.

Compressor Plant.

The compressor used for experimental purposes is a temporary affair answering fairly well for purposes intended.

The general plan of power plant and conduits, as outlined by Superintendent Todd, of the Eckington Road, consists of a central station near 10th and H streets, southwest. This location is selected to permit the use of river water, and would necessitate the use of at least two lines of pipe—one to the vicinity of 7th and B streets, northwest, and one to 13th and D streets, northeast.

In concluding the results of Mr. McFarland's investigation he finds the operation of the cars tested (Nos. 91 and 400), in the main, entirely satisfactory and suitable to the purposes intended, though he suggests a few minor changes in the arrangement of machinery, such as a slight enlargement of the diameter of the cylinders, and a reduction of wheel-bases of the cars.

The objectionable features of the fire-pot and stove-pipe in car No. 91 have been eliminated in car No. 400. The vibration of the car while in motion he does not consider serious, though the noise from exhaust air in starting and in ascending grades is quite noticeable. The danger of rupture of air bottles, while not impossible, is improbable, and decreases proportionately with the distance from the charging point. The dust arising from the motion of the car is not appreciable.

Regarding the advisability of granting permits for the equipment of these lines with air-motors of the Hoadley-Knight pattern, it has been admitted by various authorities, and notably in an interview with Gen. Herman Haupt, published in the New York "Sun" of March 28, 1897, that this system was rejected in New York city in favor of the underground electric. It has not been tested on the various sections of the roads over which it is expected to be operated. It has not been demonstrated that these cars would carry sufficient excess of power to enable them to reach the charging point in case of loss through leakage or defective machinery, or to assist a disabled car to the power house. The length of time required for recharging the reservoirs at the proposed charging points is not obtainable. It is also stated, on fairly substantial grounds, that the people who are interested in these roads are also interested in this particular system of air-motors, and consequently desire its adoption. It seems proper that a schedule should be made public, and the cars run on such schedule for a period of several successive days. The fears of the public of danger from explosion of air reservoirs should be allayed by actual tests to the point of destruction, and results published. Has such a test been made of different systems as would ordinarily be required under similar conditions by railroad men wishing to adopt a change in motive power? Are the advantages offered for the adoption of the Hoadley-Knight system sufficient to warrant its selection in preference to others in view of the following facts?

In order to get the tracks of these lines in condition to render satisfactory service, and at the same time withstand the heavy traffic incidental to the use of the air motors, I have prepared an approximate estimate of the cost of such repairs, amounting to $81,430.

Under date of November 7, 1896, the president of the American Air Power Co., of New York city, submitted a proposition to equip the two roads in question with compressed-air motors of the Hardie system, consisting of 60 cars, provided with air-brakes, Pintsch gas appliances, storage capacity sufficient for a run of at least 10 miles, with a large reserve, capable of being operated at the rate of 10 to 12 miles per hour, together with a fully-equipped compressor and steam plant, exclusive of buildings, of sufficient capacity to run all the cars continuously, and to deliver the whole equipment ready for operation within six months of date of execution of contract, for $399,000. On the basis of 80 cars, however, the receiver has computed that their price would be $574,000, which would include an allowance of $30,000 for buildings and $12,000 for pipe lines.

To this amount, however, should be added the cost of track repairs as above ($81,430), making a total cost of equipment under the proposition of the American Air Power Co, $655,430.

Concerning this system, the Hardie, it is claimed to have been in successful operation on 125th St., in New York, for the past nine months, in all weathers and conditions, without interruption, and able to run when cables and underground trolleys were stalled by storm. Cost of operation is not obtainable, but Mr. Frank Richards, M. Am. Soc. M. E., in a letter published in the New York "Sun," of May 10, 1897, states that "it can be proven and guaranteed to be lower than that of any other known system."

Under date of November 9, 1896, the President of the Compressed Air Co. submitted a proposition to equip these lines with the Hoadley-Knight system, consisting of 80 complete car equipments (exclusive of car bodies), including Pintsch gas appliances, compressor and boiler plants (including building), storage reservoirs, pipe line, etc., complete, to be furnished within 12 months from execution of contract, for the sum of $508,000.

To this also should be added the cost of track repairs ($81,430), making the total cost of equipment under the proposition of the Compressed Air Co., $589,430.

A combined proposition from the General Electric, the American Wheelock Engine Co., and E. Saxton, was submitted for the equipment of the roads with an electric underground trolley system, similar to that in use by the Metropolitan Railroad Co., of this city, making the total cost for the equipment of the roads (according to the receiver's report), $1,791,105.

I have also prepared an approximate estimate of cost of equipping these lines with the same system as above, from data believed to be reliable, based on cost of the Metropolitan R. R., on the basis of 25.5 miles single track construction, 80 motor cars, 2 power stations, with complete equipments, including cables and all necessary adjuncts, etc., amounting to $1,443,000.

The Westinghouse Electric & Mfg. Co. also submitted a proposition for equipping the roads with the Electro-Magnetic system at a cost (according to the receiver's report) of $2,075,036, to which is added the estimate of the American Wheelock Engine Co. for steam equipment, amounting to $195,000, making the total cost of Electro-Magnetic system $2,270,036.

Summary of Cost of Systems.

American Air Power Co. (Hardie).....	$655,430
Compressed Air Co. (Hoadley-Knight).....	589,430
Underground Electric (receiver's estimate).....	1,791,105
" " (private estimate)..... ..	1,443,000
Electro-Magnetic (Westinghouse).....	2,270,036

In the matter of the selection of the Hoadley-Knight system for experimental purposes by the receiver, it is but fair to state that he claims to have been actuated by the fact of the act of Congress of June 10, requiring a test of compressed air propulsion be made, and that such a test could be made under the proposition of the Compressed Air Co., for a period of 30 days, without any expense whatever, other than the value of one car body, and without any obligation to adopt that system, such favorable terms not having been submitted by any of the other concerns from whom proposals were invited. And also its apparently successful and satisfactory operation on the Lenox Avenue line in New York city, and being particularly favorably impressed with its simple and effective system of control.

Regarding the comparative cost of operation of the compressed air and underground electric systems, it is difficult to reach a definite conclusion owing to the former never having been operated other than in an experimental manner, so that no reliable data are obtainable; although, in a communication to the Commissioners from R. J. Mawhinney et al. (No. 3397, Engineering Department), it is stated: "However, we understand that the expense of running one of these air motors (Hoadley-Knight) is about 14 cts. per mile, or the same as a cable car, while it costs but 9 cts. per mile for the underground electric." In an interview with the President of the Metropolitan R. R. Co of this city, he gives the operating expenses of their lines at about 9 cts. per car mile. These estimates, however, do not include the interest charges on the funded indebtedness connected with the different systems.

From the reports of the Railroad Commissioners of the State of Massachusetts for the year 1896, I have selected five of the street railways, operated by electricity (overhead trolley system), having the nearest approach in mileage of track operated to the Eckington and Belt lines, and

find the average cost of operation, per car mile, of these five lines to be about 14½ cts.

Assuming, therefore, for the sake of comparison, that if the Eckington and Belt lines were equipped with air motors they could be operated at a cost of 14 cts. per car mile. With an equipment of 80 cars, 70 of which would be in constant operation for 18 hours per day at the average rate of 7 miles per hour, at 14 cts. per car mile, the yearly cost of operation would be $450,702, against $295,737 for the underground electric system under similar conditions, at the rate of 9 cts. per car mile, or an annual difference in favor of the latter system of $154,965.

Including the interest charges (7%) on cost of equipment under the Hardie, Hoadley-Knight and underground electric systems, a comparative statement would be as follows:

	Annual cost of operation.	Annual interest charges.	Total.
Hardie	$450,702	$45,880	$496,582
Hoadley-Knight	450,702	41,260	491,962
Underg'nd Electric..	295,737	101,010	396,747

The report of the Eckington road for 1896 shows 4,066,030 passengers carried, and of the Belt road for 1895 (report of the latter for 1896 not being available), 3,066,731, making a total of 7,132,731 passengers carried annually by the two roads, which at the rate of 4.59 cts. per passenger (the average of the Metropolitan R. R. of this city), would make the annual gross receipts from passenger traffic amount to $327,392.35. This, however, does not allow for a large percentage of increase in traffic which would undoubtedly result from the introduction of a rapid transit system on these lines.

But from reports of the President of the Metropolitan Railroad for the month of June, 1896 and 1897 (under horse and electric power, respectively), the gross receipts show an increase of 85% on the Georgetown line, and 70% on the Connecticut Ave. line. It would, therefore, seem reasonable to allow 50% increase for these lines. On this basis the gross annual receipts would amount to $491,088.52.

As to the advisability of the adoption of the Hoadley-Knight system of compressed-air propulsion in preference to the Hardie system, it is to be regretted that there are no data available showing very recent results of the experimental operation of the former in New York city. There are, however, a number of papers on file in the office of the Engineer Commissioner relative to the operation of a locomotive on this system as witnessed by Captain G. J. Fieberger, Corps of Engineers, U. S. A., on the tracks of the N. Y. Central R. R., at Rome, N. Y., February 21, 1895 (where a speed of about 18 miles per hour was maintained for a distance of 12 miles, and "not the slightest difficulty experienced in starting or stopping the car or regulating its speed"). See also communications of Gen. Herman Haupt (No. 4561) and Mr. Arthur W. Soper (No. 4926, enclosing copy of letter from the President of the Third Ave. R. R. Co. in New York city), all of which give most favorable reports of the operation of the Hardie Air Motor.

Very respectfully, Edward G. Emack.

Washington, D. C., July 16, 1897.

We append to Mr. Emack's report the following particulars of observations made by Mr. W. A. McFarland on cars of the Hoadley-Knight system, operated on the Eckington & Soldier's Home Ry., which are referred to above:

Tests of Car 91; Reservoir Capacity.

Date of run.	Distance, miles.	Pressure of air in reservoir, lbs. At start.	Pressure of air in reservoir, lbs. At finish.	Cu. ft. of free air per mile.
June 11..... ..	5.4	2,050	300	946
June 11		2,170	250	1,038
June 11..		2,000	250	946
June 11....		2,150	410	887
Car No. 400; Reservoir Capacity, About 37½ Cu. Ft.				
June 18..... ..	5.4	2,225	250	927
June 19..	3	.....	...	640
Reservoir Capacity Increased to 44.2 Cu. Ft.				
June 23	8.5	2,300	150	760
June 23..	8	2,250	200	769
Reservoir Capacity Increased to About 52 Cu. Ft.				
June 25..	8	2,050	250	800
June 27..... ..	7	2,000	350	834

Notes: Each car has a seating capacity for 30 passengers and weighs about 20,000 lbs. Motors are compound; h.-p. cylinder, 3½ × 6 ins.; l.-p. cylinder, 7 × 6 ins.; gearing, 2 revolutions of motor shaft to one of car axle; wheel-base, 8 ft.; wheels, 28 ins. diameter.

Report of Capt. W. M. Black.

To the Commissioners of the District of Columbia:

Gentlemen: I have the honor to submit the following report upon the air motor system proposed to be adopted by the Eckington and Soldiers' Home and Belt Line Railway Companies.

The act approved June 10, 1896, requires the Commissioners to judge whether the compressed air motors experimented with or adopted by the Eckington and Soldiers' Home and Belt Ry. Companies "prove to be in all respects a proper and satisfactory motive power for the speedy and convenient propulsion of street cars."

The problem presented to the Commissioners is most difficult in the absence of the exact data to be obtained only from the experience of a line in regular operation. Claims, often unreasonable, are made for and against the system of air motor propulsion in general and the Hoadley-Knight system in particular. Under these circumstances it is to be expected that whatever the conclusion attained, the evidence presented will not be satisfactorily convincing.

To meet the requirements of the act, the motors in question must be safe, comfortable, sure in operation, and adapted to the work. Attention is invited to the accompanying reports of Assistant Engineers McFarland and Emack, which present details of great interest. From these reports the following deductions are made:

Comfort.—The features which the proposed cars have in common with all of the ordinary forms of street-cars may be considered satisfactory. Those peculiar to the car arise from the motive power. Heat and fumes of combustion have been complained of in the first type of car used, and with reason. In the second type the substitution of hot water for the furnace, it is reported, has removed these defects.

The noise produced by the machinery while in regular motion is not excessive. In starting and in ascending grades, the exhaust produces a puffing sound similar to that of a steam locomotive, but not loud enough to be seriously objectionable. The weight of the car is favorable to smooth riding, and the car vibration and pitching on the wheel-base in use (8 ft.) is not excessive. It should be noted, however, that this base is too long for the curves now in the lines and produces grinding and loss of power. It can be reduced, but if reduced may increase the pitching motion of the car. The dust thrown up by the exhaust has also been complained of, but apparently with slight cause, and this can be remedied easily.

A most important factor in the comfort of passengers is a solid track. The present tracks of the Eckington and Belt Railways were not designed for motors as heavy as the air motor, and probably would require considerable reconstruction before being fit for the proposed use. It may be added that a rigid track is necessary also to preserve the pavements adjacent.

Safety.—This comprises safety to passengers and safety to passers-by. The compressed air which provides the power is carried in from 31 to 37 seamless steel Mannesmann tubes, called bottles, with a capacity of 1.2 cu. ft. each, said to be tested to a pressure of 6,000 lbs. per sq. in. They are charged with air under an initial pressure of 2,000 to 2,300 lbs. per sq. in. This pressure is diminished as the run is made. The initial pressure is approximately equal to that caused by the complete combustion of about 4.5 lbs. of pebble powder per bottle. An explosion is possible, but not probable under normal conditions, and, barring accidents, the cars may be considered to be reasonably safe to the passengers. The risk of accident is not greater than on a steam motor. The machinery is easily controlled and the danger of foreseen collision is as slight as with an electric motor. In this respect the air motor must be considered safer than the cable car. The effect on horses of the puffing of the car on grades cannot be foretold. It might easily startle a nervous horse.

Certainty of Operation.—The compressor machinery at the power station is liable to the same accidents as are common to all heavy machines, and like all machines from which a continuous amount of work is essential, must be partially duplicated at each station to secure the line from stoppages and delays due to breakdowns. When this precaution is taken and a proper reserve reservoir for air provided, there is no reason why there should be a stoppage of operation due to a failure of air supply.

Should the attempt be made to make substations for recharging, at which reservoirs are supplied through pipes from a main station, success becomes much more problematical. It has proved to be impossible to make gas mains

under a pressure of less than 20 lbs. per sq. in. absolutely tight. It is very doubtful if long mains could be laid and maintained under the streets in such manner as to conduct air under the pressures proposed (2,000 lbs. and over) without so much leakage as to render the scheme commercially impracticable. The motor machinery on the cars is quite similar to that of a steam motor and may be considered as being well adapted to the end in view, if the propelling power (air) can be controlled to the same extent as steam. This remains to be proved.

In any system, occasional complete breakdowns of machinery are expected. In all other systems there is a sufficient reserve power in each motor to tow a disabled motor from any point on the route back to the power house. Mr. McFarland's tests show that the reserve of air in the motors in question is too small to provide for this contingency with certainty.

Fitness for the Work.—This includes the question of speed, power to overcome grades, curves, etc., convenience of location of power plant, and economic suitability. The first two requisites can be met if the motors can be supplied with air in quantity and at pressures sufficient for the work. The tests show that a car in working order, supplied with sufficient air at a proper pressure, can carry the required load up the worst grades on the road, and can attain the requisite speed.

It has not been shown, however, that trailers can be used with these motors. As traffic increases trailers play a most important part in the reduction of operating expenses, and in fact may be considered a necessity, especially where unusual transportation demands must be met on special occasions.

The air motor system seems the least flexible of systems as to the arrangement of its power plant. The shortness of possible run requires recharging stations at points on the line which cannot be changed to any material extent. The companies now propose either to establish three power plant houses or to establish one main power house with two substations supplied with air from the main station through pipes laid under the streets, but each having a reheating plant. Neither alternative is advantageous to the city. The latter is by far the more objectionable besides being of doubtful practicability.

There remains the economic problem. There are 31 miles of tracks in the combined systems. For a portion of the routes they pass through the busiest parts of the city. No system should be introduced which does not give a sure promise of commercial success. The needs of the district are too great to permit the risk of commercial failure and of the consequent breakdown of the adopted system. The use of compressed air as a motive power is not new. The real problem involved in its application to street cars is how to store asupply sufficient for a prolonged run without recharging. Given a supply of air under pressure the main loss of energy in its use, in a well designed machine, arises from the cold of expansion and leakage, and these causes of loss become greater as the pressure under which the air is stored and used is increased. Ordinarily air for running machinery is delivered at pressures of less than 100 lbs. per sq. in. In the motors in question in oris how to store a supply sufficient for a prolonged run reservoirs are charged with air at a pressure of more than 2,000 lbs. per sq. in. From these the air passes through a valve designed to reduce the pressure to 200 lbs. and thence it goes to the machinery, being reheated in order to increase its expansive power. It is the necessity for these great pressures that make the motors to a large degree experimental, and this is proved by the very great air consumption per mile, as detailed in Mr. McFarland's report. If this leakage and loss is so great with new machinery, run under the condition of a trial trip, what will it be when the valves and packing become worn? No data are presented, and none could be obtained in the tests possible to make, to show what would be the effects of wear, nor how much repair is required.

Mr. McFarland's report shows that the air motor system proposed is not economical as a machine. The average horse-power required to be developed per car from the approximate estimate he makes (the only estimate possible with the information attainable) is from about 43.7 to 44.4. The average horse-power per car to be developed in an electric line varies from 20 to 25. This would show in part the reason why the operating expenses per car mile should be relatively 14 cts. and 9 cts. for the two classes of motors, as mentioned in Mr. Emack's report.

To keep a road solvent the earnings must be sufficient to meet the operating expenses plus the interest on the bonded indebtedness. Thus, in two systems a cheap plant with large operating expenses may be less economical than a more expensive plant with small operating expenses.

Taking Mr. Emack's figures of the cost of equipping the roads with the air motor system and with the underground electric system, respectively, we have the following:

	Cost of equipment.	Int. at 7%.	Operating expenses.	Total.
Air motor	$589,430	$41,260	$450,702	$491,962
Underg'nd electric..	1,443,000	101,010	295,737	396,747

Difference in favor of underground electric system, $95,215.

The above figures are not claimed to be accurate. Accurate figures are not attainable.

In conclusion, it would seem that the air motor system possesses many good qualities, but that as yet it is experimental. Being experimental, good policy would seem to forbid its installation on so large a scale as the equipment of the Eckington and Soldiers' Home and Belt Railways would require.

The system may be "in all respects a proper and satisfactory motive power for the speedy and convenient propulsion of street cars," but satisfactory evidence that it is has not yet been presented. Very respectfully,

W. M. Black,

Captain Corps of Engineers, U. S. A., Engineer Commissioner, District of Columbia.

Washington, July 17, 1897.

Report of W. A. McFarland.

To the Engineer Commissioner, D. C.:

Sir: In accordance with verbal instructions, I have the honor to submit the following report on my inspection of the compressed air motor cars now in use by the Metropolitan Street Ry. Co., of New York city, and also of those formerly used on the 125th St. line.

At the time of my visit, August 19, 20 and 21, there were two compressed air cars, fitted with the Hoadley-Knight compound motors, on regular day service between Lenox Ave. and 146th St., and 109th St. and Columbus Ave.; the route followed being Lenox Ave. to 116th St., to Manhattan Ave., to 109th St., to Columbus Ave.

These cars and motors are the same in all essential respects as the "No. 400" now in use in this city; they are run in between the "underground electrics" with which the line is equipped. The total length of run out and back is said to be five miles, with a maximum grade of 7½% on 109th St. and a grade of about 3% on Manhattan Ave. Time occupied in making round trip 36 to 40 minutes; time for re-charging with air, 2 minutes; for re-heating water in heater, 10 minutes (the pipe used for introducing the steam for re-heating is small, and is said to be a temporary arrangement only; the time needed for re-heating can, without doubt, be much reduced by a re-arrangement in this particular). Each of the two cars in use makes about a dozen round trips per day, and during the time of my observation carried passengers, made the usual number of stops, maintained speed without difficulty, and climbed the steep grade on 109th St. at a rather better rate than did the electric cars. The passenger traffic was light and the weather favorable. The only point which seemed open to criticism from the passenger's point of view, was the puffing sound from the exhaust, which was quite noticeable in starting and in climbing grades, but which could not be heard when under headway on a comparatively level track.

The following statement, showing the fall of air pressure on each of the two cars inspected, indicates possible length of run under existing conditions:

Pressure in pounds.	Car. No. 411.	Car No. 426.
Initial	2,500	2,400
At end of 2½ miles	1,650	1,850
At end of 5 miles	1,300	1,625
Total loss	1,200	1,500
Reserve	1,300	900
Greatest possible run, miles.....	10	15

The difference in fall of pressure on the two cars is due to the greater reservoir capacity of 426.

In addition to the two cars at present in use there are three others in the shop at 146th St., intended for this service, two of them being already equipped with the Hoadley-Knight motors.

Piping.—There is a line of extra heavy 1-in. iron pipe laid in the electric conduit along the above-named route, for re-charging the cars at the southern end of the line, if necessary. This pipe line was not under pressure at the time of my visit, and I was informed that it had not been during the past summer. There is, however, about the power house at 146th St. a considerable amount of 1-in. and 1½-in. pipe under a pressure (gage) of 2,600 lbs. per sq. in. An inspection of some four or five hundred feet of this piping failed to disclose any evidence of leaky joints. I was assured by several employees about the station that no trouble from leaks had been experienced. The pipe used is said to be ordinary commercial "extra heavy" iron pipe, and is connected up with "tight joint" fittings.

The street cars fitted with Hardie compressed air motors, which were formerly used on 125th St., have been withdrawn from service and at the time of my visit were in the car barn on 125th St.

These motors are simple (not compound) with inside cylinders and outside cranks, the connection between main connecting rods and crank pins being through the medium of rocker arms and rock shaft. All working parts are close to the roadbed and exposed to dust and dirt; there are said to be over a hundred wearing parts so exposed, each requiring separate lubrication.

Mr. Hardie, the inventor of the motor, operated one of the cars for a short distance back and forth on the track in the car barn, and demonstrated the fact that the motor and car were under excellent control. The cylinders are 7 × 14 ins. The cars are shorter and lighter than those fitted with the Hoadley-Knight motors and used by the Metropolitan Street Ry. Co. The line on which the cars were used is practically level except for one short steep grade; length of round trip, 4¼ miles.

The following claims are made for these cars by the American Compressed Air Power Co.: A mileage of over 30,000 with practically no breakdowns and with a cost for maintenence of only ¼-ct. per car mile. A consumption of from 360 to 490 cu. ft. of free air per mile. That cars ran during heavy snow and sleet storms, when other surface lines were tied up, with an increased air consumption of only 20%, and an increase of 20% in number of passengers carried.

A hasty inspection was also made of the Hardie locomotive now being tested on the Manhattan Elevated Ry., and of the compressor plant on Greenwich St., used in connection therewith.

From this plant to the Rector St. station is a pipe line about 750 ft. in length, and 2.7 ins. internal diameter, used for conveying air from the compressors to the locomotive; this line was under a pressure of 180 atmospheres, or about 2,700 lbs. per sq. in., and showed no signs of leakage; the line is suspended from the elevated structure, and is everywhere in sight; it also is connected with the tight joint fittings mentioned above.

It is claimed by Mr. Pettee, engineer of the American Compressed Air Power Co., that the cost of compressing 1,000 cu. ft. of free air to 2,300 lbs. gage pressure at this plant is 2.75 cts.

I enclose herewith newspaper clippings giving account of test of Hardie locomotive used on elevated road. Mr. Pettee states that the free air per mile consumed on this run was 1,900 cu. ft.

On my return to Washington a few tests were made to determine the amount of trailer load motor car No. 400 was capable of hauling. The following is a synopsis of these tests:

Aug. 24.—Air Car No. 400, Electric Motor Car No. 23 as Trailer.

Weight of air car stated as	20,000 lbs.
" " electric motor car	15,000 "
Weight of train	35,000 lbs.

Route.—Power house to Brookland, to cut, and Florida Ave. to power house.

Power house	Pressure	2,400 lbs.
Brookland, 4:00 p. m.	"	1,625 "
4th and T Sts., 4.07 p. m.	"	1,250 "
Cut and Florida Ave., 4:12 p. m.	"	1,050 "
Power house, 4:17:30 p. m.	"	750 "
Distance run		4.3 miles.
Free air per mile		1,360 cu. ft.
Air car No. 400, weight		20,000 lbs.
Trailer, weight		6,500 "
Weight of train		26,500 lbs.

Route, same as above.

Pressure at start	1,800 lbs.
Pressure at finish	550 "
Distance	4.3 miles
Free air per mile	1,030 cu. ft.
Speed, per hour (mean)	10 miles.

On Aug. 25, car No. 400 hauled two electric motor cars, Nos. 5 and 23, from the power house at 4th and T Sts., N. E., to "cut" and Florida Ave. and return. Time, 11 mins.; distance 1.5 miles; maximum grade, 5%. Subsequently three box trailers were added to the train and hauled from 4th and T Sts. to 4th St. and Bunker Hill road and return. Time, 17 mins.; distance, 3.6 miles; maximum grade, 4¼%.

On Aug. 26 a train of eight cars, consisting of air motor No. 400, electric motors Nos. 5 and 23, and five box trailers, was hauled over the same route at a fair rate of speed. Total weight of train stated as 82,000 lbs.

Several trials show that the maximum speed of the air motor car, running light, is considerably in excess of that of the electric trolley cars on the same route; these speed trials were made in running up the grade on 4th St., N. E., from Albany St. to the top of the hill, maximum grade 4½%.

Very respectfully, your obedient servant,

W. A. McFarland.

Washington, D. C., Aug. 24, 1897.

ENGINEERING NEWS.

October 7, 1897.

THE COMPARATIVE ECONOMY OF COMPRESSED AIR AND ELECTRIC TRACTION.

The series of papers printed elsewhere in this issue concerning the use of compressed air for the motive power of elevated and street railways furnishes some data which may be useful in the discussion of the question whether or not compressed air offers enough advantages over electricity to warrant its extensive adoption for urban railway traction.

Gen. Haupt's letter presents some figures showing the cost of steam locomotive traction on the Manhattan Ry., in New York city, which may be accepted without further argument as showing the superiority of compressed air to steam for motive power on such a railway. Steam locomotives need no longer be considered as in competition with either air or electricity. Their high cost for fuel, water and repairs, together with the nuisance they maintain in the streets of a city, put them out of the race. The question now is not between steam and air, but between air and electricity.

We agree with Gen. Haupt's statement that the data are not available for a full detailed estimate of the cost of plants and operation of the elevated railways of New York with steam, compressed air and electricity, but we are not yet prepared to agree with his further statements that the data are sufficient to indicate a decided economy in the use of compressed air as compared with electricity. The case for compressed air remains to be proven, and more data than are yet available must be procured before the proof can be made.

The first question that arises concerning the relative merits of compressed air and electric traction is the relative cost of fuel, or what practically amounts to the same thing, the relative efficiencies of the two motive powers. In both systems we begin at the coal pile, and waste a certain amount of the heat energy in raising steam and in using it in steam engines. In both systems the cheapest fuel may be used. The kind of boilers

and engines may be the same, the location of the central station at a point where fuel and ashes may be cheaply handled may also be the same, and the indicated horse power in the steam engines may be obtained at the same cost, or perhaps slightly less with the compressed air system, since the momentary variations of load upon the engine are much smaller. But in the transformations of energy which occur between the engine cylinder and the car axle, the efficiencies of the several parts of the apparatus of the two systems vary considerably, and more experimental data than are yet available are needed before an accurate comparison of efficiencies can be made.

In regard to the efficiency of compressed air the following computation has been furnished us by Gen. Haupt:

Efficiency of Compression to 2,000 lbs. per sq. in. and Reduction to 100 lbs. per sq. in. in Air Motor.

	HP.
To compress 1 ft. free air per min. to 2,000 lbs. per sq. in. requires	0.40
To compress 1 ft. free air per min. to 100 lbs. per sq. in. requires	0.17
Loss in wire-drawing	0.23
0.17 ÷ 0.4 = 42.5% utilized; 0.23 ÷ 4 =	57.5% lost.
Efficiency of compression	80%
Utilized of this	42.5%
Net efficiency, .425 × .80 =	34.0%
Doubled by reheating	68.0%
Efficiency of motor	80%
Net efficiency of motor, .68 × .80 =	54.4%

It will be observed that the above computation assumes that the efficiency is doubled by reheating, but no account is taken of the cost of this reheating. We may supply a rough estimate of this cost as follows: The efficiency can only be doubled by doubling the volume of air entering the motor, the pressure remaining constant, and this would require the temperature to be increased 460° F., 1 cu. ft. of free air weighing 0.08 lbs., and its specific heat being 0.24, heating it 460° F. would absorb 0.08 × 0.24 × 460 = 0.873 B. T. U., which is equivalent to 0.873 × 778 = 680 foot ponds of work per minute, or 0.021 HP. It would require a very good heating furnace to give an efficiency of 50%, so to furnish this 0.021 HP. to the air in the motor would call for a fuel consumption equal to the heat equivalent of 0.042 HP. The compression of the 1 cu. ft. of air per minute required originally the expenditure of 0.40 I. HP. in the cylinder of the steam engine. To this should be added the cost of reheating, or 0.042 HP., making 0.442 HP. The motor delivers, according to Gen. Haupt's figures, 54.4% of 0.40, or 0.2176 HP. Dividing this by 0.442 gives an efficiency of 49.2%, instead of 54.4%.

Gen. Haupt's figures assume an efficiency of 80% for the motor. There is no doubt that this efficiency may be obtained in a well-constructed motor when it is operated at or near its most economical load, but the load on a locomotive is exceedingly variable, and its efficiency must vary within wide limits as the load varies from minimum to maximum. We should consider it remarkable if the efficiency should average as high as 80% for all conditions of loading.

It may be interesting to compare the figures given above to those which were published extensively some years ago concerning the operation of the Popp compressed air plant in Paris. In this plant the air was compressed only to 6 atmospheres (absolute), or 73 lbs. per sq. in. gage pressure, and consequently the operation did not entail nearly so great a loss due to cooling of the compressed air as if it had been compressed to 2,000 lbs. per sq. in. On the other hand, the efficiency of the compression machinery and of the motors were both lower than those given in Gen. Haupt's statement, and the reheating caused a gain of less than 40%, instead of 100%.

The figures for the Paris plant are as follows:

Efficiency of a Compressed Air Power Plant. From Tests of the Popp Compressed Air System in Paris, 1891.

1 I. HP. at central station engine = 0.845 I. HP. in compressors.

This corresponds to the compression of 348 cu. ft. of air per hour from atmospheric pressure to 6 atmospheres absolute.

This 0.845 I. HP. will deliver as much air as will do 0.52 I. HP. in adiabatic expansion after it had fallen to the normal temperature of the mains.

0.52 I. HP. power of the air at the station, reduced to
0.51 " by fall of pressure in the mains (5 kilometers)
0.50 " by fall of pressure to 4½ atmospheres (absolute) in the reducing valves,
0.39 " by incomplete expansion, wire-drawing and other causes, reducing the actual I. HP. of the motor, when the air is used cold, to 0.39 I. HP. This is increased by heating the air to about 320°F. to
0.54 " Ratio of gain = 0.54 ÷ 0.39 = 1.38, supplied by the combustion of about 0.30 lbs. of coke per I. HP. per hour. If this be taken into account, the real efficiency of the whole process becomes 0.47, instead of 0.54.
0.47 " obtained in motor from 1 I. HP. in steam engine in central station, taking into account cost of reheating the air.

Indicated efficiency of motor.....0.39 ÷ 0.50 = 0.78
Indicated efficiency of whole process with cold air....0.39
Apparent indicated efficiency of process, heated air...0.54
Real indicated efficiency, whole process,with heated air0.47
Mechanical efficiency of motor.....cold, 0.67; hot, 0.81

The final indicated HP. of the motor is only 47% of the indicated HP. of the steam engine, or 2% less than the figure given by Gen. Haupt (after we have revised it for the cost of reheating), for the net efficiency of the motor. If the mechanical efficiency of the motor, as given in the French figures for hot air, is 0.81, then the mechanical power delivered by the motor for each 1 HP. in the steam engine is only 0.81 × 0.47 = 0.38 HP.

For a fair comparison of the computed efficiency of the compressed air system with electrical traction we may take the data given in Mr. M. H. Gerry's recent paper on Electric Traction on the Metropolitan Elevated railway of Chicago, published in our issue of Sept. 16, 1897. For a 4-car train running at an average speed of 13.3 miles per hour, including stops, with an average current of 138.3 amperes and 504 volts at the train, he gives for the electrical HP. at the generating station 101 HP., transmitted to the train 93.4 HP., and utilized in propelling the train 51.5 HP., making an efficiency of 51% from the generators to the car axle. Taking the efficiency of the generators at 92%, which Mr. Gerry gives as a fair "all-day efficiency," the I. HP. used by the generators would be 101 ÷ 92 = 110 I. HP., and the net efficiency from the engine to the car-axle 51.5 ÷ 110 = 47%.

If we may admit that it is possible by the use of very efficient compressors, reheating furnaces and motors to realize with compressed air a net efficiency at the car-axle, under conditions of fairly uniform loading, of 40%, the best that can be said in favor of the fuel economy of the compressed air system is that it is equal to that of the electric system as used in Chicago. Whether it should be used in preference to electricity will then depend upon other conditions than its fuel economy. These conditions will vary on different lines of railway. On a level road with a long distance between stations the energy exerted by the motor will be approximately constant; a most favorable condition for the air motor. With frequent stops and frequent sharp grades the energy exerted will vary from zero to the maximum of which the motor is capable. This condition is easily met by electric motors. It seems to us a question whether it can be well met by air motors.

In the cylinder of the air motor, as in that of the steam engine, there is a point in the stroke

at which the cut-off must take place in order to give the maximum economy. With a very early cut-off, corresponding to light loads, the air will expand to a pressure below that of the atmosphere, producing an indicator card with what is known as the "loop diagram." With a heavy load, such as that due to climbing a grade or to accelerating the speed, the card will have a high terminal pressure. Both of these conditions mean low economy.

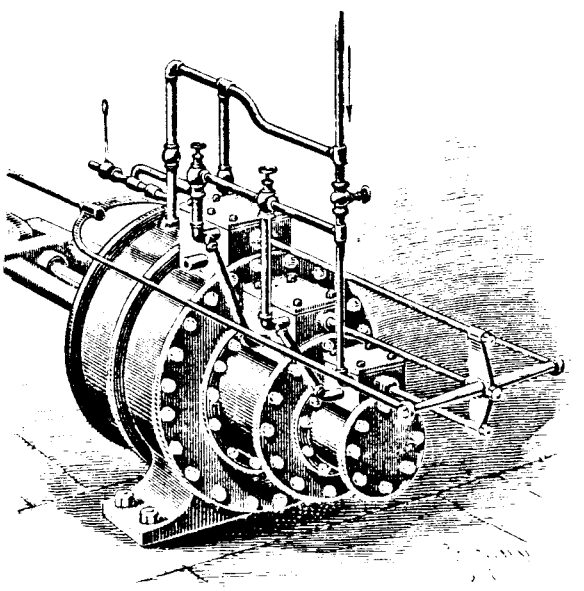
Even if the question of fuel economy may be shown to be not unfavorable to the compressed air system, there are questions concerning the practical operation of air motors in which electric traction seems to have an advantage. In a high speed rapid transit line with frequent stops, rapid acceleration of speed is of the utmost importance. With an air locomotive this requires great weight for adhesion, and large cylinders to supply the power. Large cylinders, proportioned for economical use of air at maximum loads are very wasteful at light loads. Part of this disadvantage may be overcome by using moderate-sized cylinders, and very high initial pressures for heavy loads and reducing the pressure for light loads, but it will require a long series of experiments to determine what sizes of cylinder and what initial pressures should be used for different conditions of running to give the maximum economy. In electrical traction the great weight of locomotive necessary for adhesion is avoided by dispensing with the locomotive and by using the weight of the motor car for adhesion. In the Sprague system, with a motor on each car, the required adhesion is easily obtained, and at the same time the maximum power of all the motors is available for rapid acceleration. It does not appear probable that any system of air locomotive traction can compete with the Sprague system in giving the acceleration which is so important in elevated railway service.

On the other hand, compressed air traction has some features of advantage over electric traction. One is its facility for storing power during times of light loads, without any cost of deterioration of the storage apparatus, which is the great defect of the electric storage battery. It is likely, however, that any large storage capacity could be obtained only at great cost of installation. Another, and probably the most important, as appears from the estimates of cost given in the reports on the proposed installation in Washington, is a lower first cost of plant, and consequent interest charge. These estimates, however, are for a surface street railway, in which the underground trolley system and the electro-magnetic underground system are the only systems of electric traction proposed. For elevated railways the third-rail system, which is no doubt vastly cheaper in cost of installation, would probably be used.

For an existing line of elevated railway, such as those in New York and Brooklyn, where steam is now used, and a change to electric or to air traction is contemplated, it would appear that air traction might be introduced tentatively, in an experimental way, at a cost, and an inconvenience to traffic while making the change, far less than that required to introduce electric traction. A small compressing plant might be built and a few air locomotives used which could take the place of a few of the steam locomotives. An accurate account of the cost of the operation of the air locomotives could be kept and compared with the cost of operating steam locomotives, and with the cost of electric traction on the Chicago elevated railways. A six months' trial on a moderate scale should be sufficient to settle the relative merits of steam, air and electric traction, and then if air traction should be found the best, it would be easy to enlarge the compressing plant and to build more locomotives, with such modifications in the original design as the results of the experiments might indicate.

AN IMPROVED AIR MOTOR.

The motor shown in the accompanying illustration is designed to facilitate the application of compressed air for propelling street cars, it being contemplated that compressed air shall be supplied from stand pipes communicating with pipes laid along the car route. The improvement has been patented by George H. Cooper, of New Westminster, B. C., Canada. The invention provides for obtaining a compound effect, using air at the same pressure it has in the reservoir, which is connected by a valved pipe with the valve-controlled inlet ports of a high pressure cylinder. The exhaust port from this cylinder is connected with similar inlet ports of an intermediate cylinder, and the exhaust port from this cylinder is similarly connected with a third or low pressure cylinder, the slide valves of all the cylinders being operated in unison, and the pistons being all secured to a common piston rod connected to the driving mechanism. On this rod is also secured a piston working in an air compressor cylinder, which is connected by pipes with the supply pipe, the compressor being operated only by the excess of power above that required for the work being done. The compressor thus acts as a brake, particularly on a down grade, as well as serving to partly replenish the supply of compressed air. The motor is designed to effect an economic utilization of the air at the reservoir, dispensing with a reducing valve, affording also an easy control of the speed and a powerful braking action.



COOPER'S AIR MOTOR

Scientific American.

May 28, 1898.

AIR MOTORS FOR STREET RAILWAY TRACTION.

An important street railway plant, whose operation will be watched with considerable interest, is about to be installed in this city on a portion of the lines of the Metropolitan Street Railway Company. It will be remembered that a few miles of this company's extensive lines have been operated for some time by compressed air motors, which are of the compound type and built under the Hoadley patents. On another stretch of road in this city the Hardie compressed air motor has been in successful operation. The distinctive feature of the Hardie motor is the use of a tank of hot water to heat the compressed air before it is used in the cylinders. A fully illustrated description of this machine will be found in the SCIENTIFIC AMERICAN for August 15, 1896, where it is shown in service on the lines of the Third Avenue Railway Company, New York; another motor of the same type built for the elevated roads was illustrated in the SCIENTIFIC AMERICAN of January 30, 1897.

The new plant will include a power house on the property of the Metropolitan Company in West Twenty-third Street opposite the Pennsylvania terminal, and in addition to the power house the contract calls for the equipment of twenty cars with compressed air. The air compressor will be of the Ingersoll-Sergeant four-stage single-acting type, provided with intercoolers between each pair of cylinders and a final cooler after the fourth-stage cylinder. The air cylinders will be vertical and will be set under a vertical cross-compound Allis engine.

It is interesting to note that the American Air Power Company, to whom the contract has been let, was formed by a combination of the Hoadley-Knight and Hardie Companies. The new plant and equipment will embody the experience gained by the two experimental lines to which reference has been made above, and as both of these tests have shown satisfactory results, it is safe to say that the new Twenty-eighth and Twenty-ninth Streets equipment will represent the very latest advance in compressed air traction. The Metropolitan Street Railway Company has now in operation four different systems: the cable, underground trolley, compressed air and the horse car. The probabilities are that of these four, two only will survive—the underground trolley and compressed air; the former being used on what might be called the trunk lines running north and south on Manhattan Island, and the compressed air motors working the crosstown branches.

STREET RAILWAY JOURNAL.

February, 1898.

Consolidation of Air Power Companies

The American Air Power Company, of New York, has just been formed with a capital of $7,000,000, by the consolidation of the American Air Power Company, of New Jersey; the General Compressed Air Company, of New Jersey, and the Compressed Air Power Company, of New York. The two companies first named are those which have been engaged in developing the Hardie motor. The third company, namely, the Compressed Air Power Company, of New York, controls the Hoadley-Knight motor. It is the intention of the new company to put several compressed air motors into actual operation where they will meet all the difficulties of city traffic and in this way to prove just what can be effected from this motive power. It is understood that the principal experiments will be carried on in New York City. The company has also shipped two motors to Copenhagen, Denmark.

ENGINEERING NEWS.

February 10, 1898.

*Abstract of a paper read by Mr. E. P. Lord, Superintendent of H. K. Porter & Co., Pittsburg, Pa., before the Anthracite Coal Operators' Association in New York city. The complete paper is published in the "Bulletin of the Association," which can be obtained of the Secretary of the Association, Mr. Henry S. Fleming, 26 Cortlandt St., New York city.

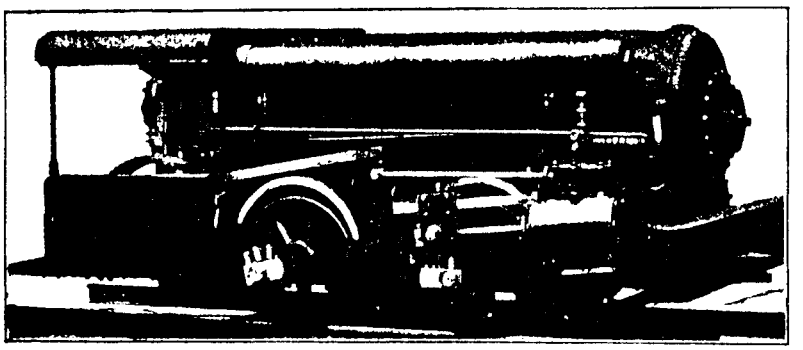
MINE HAULAGE BY COMPRESSED AIR.

Compressed air has marked advantages over any other class of haulage, in that it is free to go wherever there is a track laid; the distance run with one charge of air is only limited by the capacity of the motor tanks. Great advancement has been made in the improvements of compressors, pipe lines, pipe connections, motors, methods of charging, etc.; so that for efficiency it is admitted that compressed air runs electricity very close for a long-distance transmission. It is equally efficient and safe in fiery and non-fiery mines, and materially assists ventilation by the air given out by the exhaust. Efficient ventilation must be provided for, in any case; but compressed air is now used for driving mining machines in rooms or in butt entries, ahead of the general work and beyond the range of general ventilation.

Compressed air recommends itself also for many other practical advantages, such as moderate cost of plant and installation, due to the absence of overhead wires or obstructions; economy of operation, secured by durability of construction; convenience and simplicity of operating and management; minimum risk of delay from breakdown or derangement; exceptionably low cost of maintenance; safety, due to the large factor of safety of all parts subject to strain, and the practical impossibility of over-charging; the absolute absence of fire, thereby enabling it to be used without risk, where steam or electricity is equally objectionable; cleanliness and quietness with which it can be operated, and flexibility, adapting it to almost any requirements. Again, it can be adapted to any varying requirements of service, so that the entire plant can be run economically at only a fraction of its full capacity, no more power being generated than is needed for the work to be done.

Compressed air locomotives are designed and constructed for a very wide range of service. Some of the principal uses are as follows:

Underground haulage in mines, whether worked by shafts or slopes, hauling trains through tunnels and city streets, transporting material at industrial establishments; also in various manufactories of an extra hazardous nature, where there are any special fire risks; general haulage, where



COMPRESSED AIR LOCOMOTIVE FOR PEERLESS COAL & COKE CO., VIVIAN, W. VA.

fuel is expensive and water power available; street railways in large cities.

The air for mine locomotives is stored in one or two steel tanks having a cubic capacity designed for the length of run, weight of train, grades, etc. These tanks usually occupy the space that the ordinary boiler does on the steam mine locomotive. They are constructed with a large factor of safety, and are tested to a much higher working pressure than they are designed to carry. The air from the main tank or tanks is conducted through copper pipe connections to an auxiliary reservoir of suitable diameter. The pressure in this auxiliary tank can be regulated (usually 150 pounds) anywhere from 30 up to 300 lbs., as required. The air is reduced and controlled from the main tanks by a reducing valve and stop valve, which can be regulated to any pressure at a moment's notice; and when once set, maintains a constant, fixed pressure (usually 150 lbs.) in the auxiliary reservoir, thereby preventing any undue waste of air, unnecessary slipping of driving wheels, etc., by injudicious handling. In case only light loads are to be handled, the pressure can be materially reduced in the auxiliary reservoir. On the other hand, in emergencies the higher pressures can be at a moment's notice utilized. In the auxiliary reservoir the air is controlled and delivered to the cylinders by a differential throttle valve. The port openings in the cylinders are specially designed for the use of air, and there is absolutely no back pressure in the cylinders, no matter at what load the engine is working, and no trouble is ever experienced from the freezing of the exhaust.

The actual cost of operating the first plant we installed in the Anthracite region was found to vary from 1 to 1¼ cts. per ton, mile net weight hauled, including all expenses, interest and depreciation of plant. The saving by the use of compressed air over mule haulage being equal to the entire cost of plant in 2¼ years, averaging 204 working days each, one locomotive being used to only one-half its capacity, and the other about one-fifth of its capacity. To operate both motors to their full capacity, and also the compressor, would add very little to the steam, lubrication, repairs, etc., but would reduce the cost of operating even below these figures.

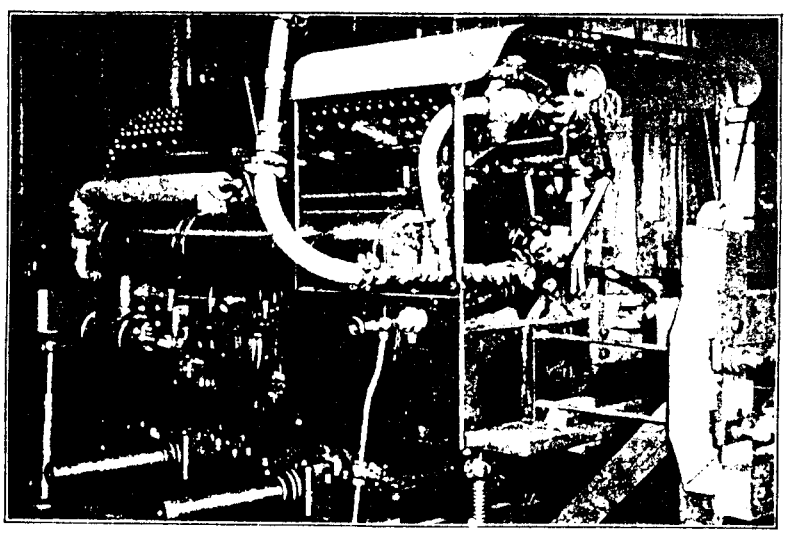
In installing a compressed air plant the most important items of installation are the boilers, compressor, pipe line, charging station and motor. The size and capacity of these various units depend upon the physical characteristics of the mine and the required output in tons of coal per day. Upon the number of times that the motor is to receive a full charge of air per hour, is based the capacity of the compressor, while the pipe line serves as a storage reservoir for storing up air while the motor is in service. The pipe line should be of such diameter and length as will give a cubic capacity of air at a certain pressure, sufficient to equalize immediately in the tanks of the motor when connection by couplings is made. In the old principle of installation pipe lines were not generally used, but large, expensive air receivers were substituted, and the motor generally took its charge of air from them direct and then made its round trip. In all plants we recommend the laying of pipe lines of a certain cubic capacity; the size and length of pipe depending largely upon what points in the mine it is necessary to reach in order to arrange charging stations so that the motor can conveniently receive its charge of air without any delay.

There is an erroneous idea that considerable time is lost in charging a compressed air locomotive; while in fact the largest motors which we have constructed can be brought to a standstill, the couplings made and broken, and the full charge of air received in a minute to a minute and a half.

Below is a list of a few of the different types of compressed air locomotives which we have designed and installed.

Two 7 × 14, class B motors, Susquehanna Coal Co.; 5 ft. 3 ins. wheel base, 36 ins. gage, 130 cu. ft. capacity of motor tanks; weight in running order, 18,500 lbs.; length over all, 17 ft. 6 ins.; width, 5 ft. 2 ins.; height, 5 ft.; working pressure, 600 lbs. This locomotive hauled a trip of 16 empty cars (about 2,500 lbs.) from foot of shaft, 3,700 ft. into gangway, and trips of 16 loaded cars (each with about 6,700 lbs. of coal), back to the shaft, with one charge of air; starting with a pressure of 575 lbs., and ending with a little over 100 lbs. The heaviest work is hauling empty trips up grade. Average grade, 1.07%; maximum grade, 2.8%, in favor of loads. The weight of each empty trip with 16 cars, including locomotive, is about 60,000 lbs.; and of a loaded trip, including locomotive, 166,000 lbs. This locomotive makes from 25 to 50 miles per day, depending upon the length of the run and the time required for making up trips. At 20 trips per day, the output amounts to about 1,070 tons, and with one motor. Approximate cost of such a plant, all complete, $12,000 to $14,000. This includes cost of compressor house and foundations and material for same; all steam connections; 6,000 ft. of 5-in. pipe, 4,000 ft. of 3-in. pipe; compressor and two locomotives.

We have recently completed for the Rochester & Pittsburg Coal & Iron Co. two 9½ × 14 class C locomotives, having 5 ft. 6 ins. wheel base; 6 drivers, 26 ins. diameter; weight, 28,000 lbs. in working order; capacity of the two motor tanks, 187 cu. ft. of air at 600 lbs. maximum pressure; height, 5 ft. 3¾ ins.; width over front bumper, 74 ins. for 42-in. gage; width over tanks, 72 ins.; length over bumpers, 19 ft. 5¼ ins. These locomotives are designed to run on 30 and 35 ft. radius curves, and are to run on a 25-lb. rail, which they can do very safely. Where the rails are light we recommend a six-wheel type. The locomotives are of our recent design, and have given exceptionally satisfactory results. They are running a distance of 6,000 ft. on butt headings, or 12,000 ft., round trip, with one charge of air. They are hauling over a 4% grade with empties weighing 1,600 lbs. each, and 22 to 28 cars per train; cars holding about 2 tons each. Total weight loaded



COMPRESSED AIR LOCOMOTIVE FOR THE ANACONDA COPPER MINING CO.
(On Testing Stand in the Shops of H. K. Porter & Co.)

train including locomotive, 92 tons. The first locomotive we built for these people, in 1892—a very crude machine compared to our present design—runs 5,900 ft. from place of charging, with empties, and return with loads, making round trip of 11,000 ft. with one charge of air and hauling 22 cars each way.

We have also completed the installation of a number of plants in the anthracite territory, notably, two 7 × 14 class B motors, for the Mill Creek Coal Co.; one 10½ × 14 for the Cross Creek Coal Co., Drifton, Pa. Plants recently completed in the bituminous districts are, one 8 × 14 class B motor for the Mount Carbon Co., West Virginia; and the Carbon Coal Co., Greensburg, Pa., one 8 × 14 class C motor.

We built a 5 × 10 class B motor for a large copper mining company in Montana, which had a 3-ft. wheel base, and designed to run on curves of 12 ft. radius; for 18-in. gage; four drivers, 23 ins. in diameter; weight in working order, about 10,000 lbs.; 47 cu. ft. of air, 550 lbs.; height, 58 ins.; width, 58 ins. over cab; length over bumpers, 10 ft. 4½ ins. This motor was equipped with a re-heater, and we made a special test of the same in our shops in order to ascertain the relative efficiencies when working under cold and hot air.

The economies of compressed air haulage are best obtained by using the air expansively in the cylinders. The tendency is usually to work a motor up to its highest practical capacity, allowing the air to follow the piston the greater part of the stroke. This means decreased expansion in the motor cylinders and less efficiency than could be obtained with larger cylinders and greater expansion of the air. It is very essential that the total weight of the motor in working order should be somewhat in excess of what is the general custom with steam locomotives, inasmuch as there is always at hand a higher pressure than the working pressure, which can be utilized, provided a fair margin has been allowed for weight on drivers. It is our custom to make our engines considerably heavier than is ordinarily followed in locomotive construction generally. Not only does the frictional resistance of mine cars frequently run extremely high, but greasy and wet rails, poor line and surface are disadvantages which very largely contribute to the slipping of locomotive drivers, and emphasize the great importance of not depending upon too low a coefficient for weight of motor to tractive force of same. For best results we have assumed that the tractive force must be equivalent to one-fifth the weight of the motor.

Size of Motor and Energy Required for Stated Trains and Length of Run.

In order to determine the proper size of motor, and tank capacity for the same, it is in most cases necessary to figure out the energy required in foot-pounds for doing the work. The factors entering into this calculation are: (1) Frictional resistance—usually 20 to 40 lbs. per ton, depending upon the condition of track and rolling stock; (2) Grade resistance—20 lbs. per ton for each 1% of grade; (3) the curve resistance, depending upon the length and sharpness of curves; (4) weight of empties and weight of load; daily output in given pounds, and most desirable size of train.

Having determined the weight of train, the daily output and the severest conditions of grade, etc., the size of motor required, the next point to determine is the size of storage tanks on motor, sufficient for making certain round trips between charging points with one charge of air. In order to make a correct estimate we should know the grades and conditions for each varying section of track.

For mine service there are few motors at present built for a pressure higher than 700 lbs. per sq. in. When long runs are necessary between charging points—say, 1½ to 2 miles, it becomes necessary for the usual size of mine motors to carry a higher pressure in the motor tanks, say 750 to 800 lbs.

In connection with these higher pressures, it is often possible to heat the air, in order to obtain the greatest possible work from them. This heating can be done either by direct heater, or by injecting steam into the auxiliary tank while the motor is being charged with air. When the auxiliary tank is employed as a heater, it is from a half to two-thirds full of hot water and steam, and the air made to pass through the same on its way to the throttle and cylinders. Again, the moisture taken up by the air when heated by hot water helps materially to lubricate the cylinders and valve surfaces. If air at normal temperature in a pipe line is re-heated, and thereby expanded, the additional volume of air resulting from the expansion is produced by an expenditure of heat much lower than the original volume of air was compressed for, and by a much lower expenditure of heat than is required to produce an equal volume of steam.

Pipe Lines.

Frictional resistances in pipes conveying fluid are proportional to the density of the fluid; consequently, at equal velocities, the frictional resistance of air is enormously less than that of water. Air may be transmitted in mains, without serious loss or fall of pressure, at ten to twenty times the velocity practicable with water in water mains. Air at 90 lbs. is 115 times lighter than water, and frictional resistance at equal velocities is less than 1% of that of water. In air mains velocities of 25 to 50 ft. per second are allowed without serious frictional loss. In consequence of this high velocity, large amounts of air power can be transmitted by air at moderate pressures in pipes of moderate dimensions.

In the installations we have made, we have never found it necessary to recommend anything above 6 ins. in diameter; 5 ins. has been the size of pipe most utilized, and as low as 2 and 3 ins. We have found that in pipe lines of a mile or over, the difference in pressure at both ends has been hardly appreciable.

Compressors.

Where the air is to be compressed to the high pressures necessary to pneumatic haulage installations, we recommend the use of the compound principle of compression. Single compressors have an increasing resistance with the advance of the piston, and increasing temperature of the air, and it is quite necessary to equalize in some manner this vast difference in pressure. The compound compressor secures more uniform resistance at all points of the stroke, and is by far the most economical and efficient machine for mine service.

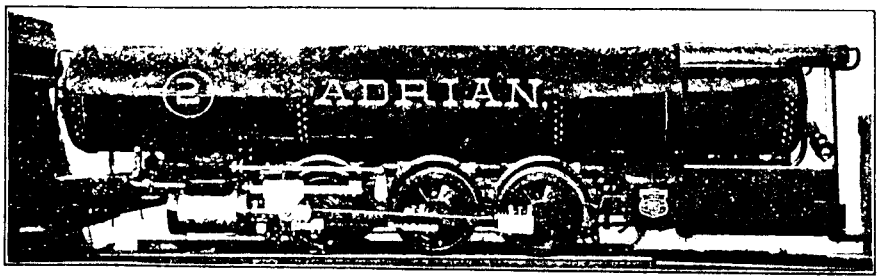
In the test made of the compressed air installation of the Susquehanna Coal Co., the air from the three-stage compressor—taking air from the atmosphere and compressing it to 600 lbs.—was only 180° at the point of discharge. This shows the manifest benefits of compounding and proper intercooling. Some of the best designed three-stage compressors, compressing to 2,200 lbs. pressure, the air, after undergoing the three stages of compression, shows a final temperature after leaving the last or high pressure cylinder of 336°; this with the temperature of the intake air at 60°.

There has been some little discussion going on of late on the subject of explosions and fires in air compressing engines and air receivers. In every case the cause of explosion or ignition is unquestionably due to an increase of temperature above the flash point of the oil which is used to lubricate the compressor. Thin oil, with high flash point, and as free from carbon as is consistent with good quality, should be used. We believe that the cases that have occurred in general practice have been wholly confined to the single acting compressors, and not the compound type. If compound compression was specified for all mine pressures above 60 lbs., the result would be low temperatures and better results. Some of the trouble may be traced to a manifest increase in the temperature of the incoming air, which is made excessive by the sticking of one or more of the discharge valves, thereby allowing some of the hot compressed air to flow back into the cylinder, and in that manner influencing the temperature before compression. It has been pointed out that the discharge passages or discharge pipes in course of time will accumulate a deposit of carbon from the oil, which will so constrict the passages that the volume of air delivered to the compressor is much impeded.

Efficiencies.

By the word "efficiency" we mean the percentage which the power given out by the motor bears to the power required to compress the air in the compressor. The ultimate power developed at the motor is frequently a small percentage of the power expended. In many cases the losses are due to poor designing and faulty installation, and cannot be directly charged to faults of the system or bad workmanship. If we were to make a careful test of a compressed air mine plant, including the indicating of

the pumps, hoisting engines, drills, etc., we might be surprised at the low horse-power resulting, as compared to the indicated horse-power of the compressor. We might arrive at an efficiency as low as 25% to 35%, which would perhaps appear unfavorable and misleading, did we not take into consideration the manner in which the power is



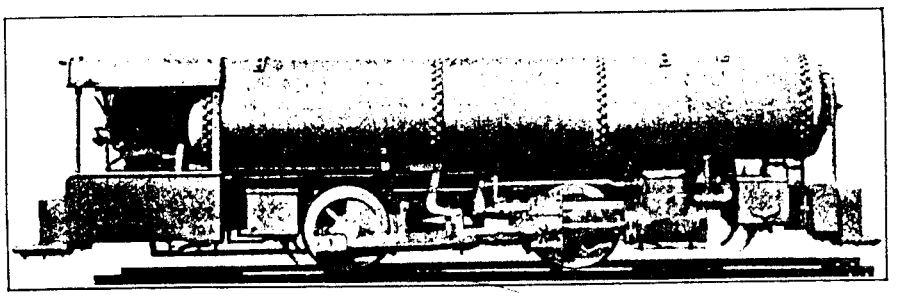
THREE-DRIVER TYPE OF COMPRESSED AIR LOCOMOTIVE.

used. Indicator diagrams from almost all the pumps in use would take the form of a perfect parallelogram, with a terminal pressure equal to the initial pressure. This condition of things is also true in the hoisting engines or drills. Of course, these machines would use steam under the same wasteful conditions, and would show a correspondingly poor efficiency if compared with the same volume of steam used expansively in an economical engine. The air locomotive uses the air expansively, and its efficiency is correspondingly increased.

As regards the losses that are frequently chargeable to a compressed air plant, one compressor builder very concisely expresses them as follows:

1st.—Friction of compressor—amounting ordinarily to 15 or 20%; never probably reduced below 10%. 2d.—Loss occasioned by pumping air drawn from the engine room instead of from the outside or some other cooler place. This loss varies with the seasons, the amounts varying from 3 to 10%. This can all be saved. 3d.—Serious losses arise in the compressing cylinder. Insufficient supply, difficult discharge, defective cooling arrangements, poor lubrication, and no end of other causes perplex the designer and rob the owner of power. The fourth loss is found in the pipe line. No leak can be too small to require immediate attention.

By adopting recent designs, with all the latest improvements, the cubic feet of air compressed per hour per horse-power has been raised from 264 to 367—a decided advance. The power can be transmitted, say at a pressure of 60 lbs., to two miles distance with an efficiency of 50% on the indicated horse-power of the compressor engine; this without reheating. By heating the air this efficiency may be raised to 70%.



COMPRESSED AIR LOCOMOTIVE FOR SUSQUEHANNA COAL CO., NANTICOKE, PA.

Pneumatic motors under most adverse conditions have been able to show efficiencies between 30 and 40% with cold air.

When it is understood that compressed air motors carrying 600 to 750 lbs. of air can run a distance of from a mile and a half to three miles, according to physical conditions of mine, and with one charge of air, the question is often asked why higher pressures cannot be used with economy, so that the motor may never require to charge except at one most convenient point in the mine system. If we were to resort to higher pressures, say 1,500 to 2,500 lbs., we would have to substitute Mannesmann tubing for the tanks at present constructed. This means much increased cost, as the price of this tubing, now made only in Germany, is very high. And again, a proper storage system, either in pipe line or receivers, would be necessary in order to charge the motor promptly. Therefore there would be no saving in cost of installation. Where the height of entry is limited, high pressure motors as above could be used advantageously, but at an increase in first cost. They could be constructed to meet the same limited heights as electric motors.

Recent Improvements in Mechanical Traction for Railways

Upon this subject E. A. Ziffer, civil engineer of Vienna and president of the Bukowinaer Localbahnen, read a very interesting paper before the International Street Railway Association at its tenth annual meeting in Geneva, during August last. The object of the paper, as expressed by Mr. Ziffer, was to rehearse briefly the improvements made during the last two years, since the presentation of his paper on the same subject before the same society in Stockholm in 1896. This paper was published in the STREET RAILWAY JOURNAL for January, 1897. A digest of Mr. Ziffer's last paper is given below:

GENERAL

The system most generally in use in Europe as well as in America is the overhead trolley, which in Europe on Jan. 1, 1898, was employed on 172 lines out of a total of 204 employing electric power. Mr. Godfernaux, in his book "Mechanical Traction for Tramways," gives the following theoretical comparison of the cost of the different systems, including 10 per cent of amortising fund, on the capital invested, and based upon an annual traffic of 1,000,000 car km. The figures are in francs per car km.

SYSTEM OF TRACTION.	EXPENSES.		
	Operation.	Amortization.	Total.
Rowan	0.35	0.11	0.46
Serpollet	0.30	0.11	0.41
Gas motor	0.43	0.11	0.54
Compressed air	0.42	0.15	0.57
Electric accumulators	0.34	0.13	0.47
Trolleys	0.31	0 17	0.48

Mr. Schiemann, who has made a thorough study of the operation of electric lines in Germany and Austria, concludes that of the three electric systems (trolley, underground conduit and accumulators) the trolley is the most economical and accumulators next, and the combination of the trolley and underground system is always more satisfactory than the combination of trolley and accumulators.

CONCLUSIONS

Steam motors have been much improved recently in America. They are important factors for branches of steam railways as well as for tramways where the traffic is not sufficiently important and remunerative to warrant the operation of locomotives and complete trains and where the local conditions are prejudicial to an electric system. Among the steam motors, the Serpollet has certain advantages which have resulted in its extended adaptation, particularly in France, but there are nevertheless certain inconveniences attached to the system which the manufacturers are making an effort to overcome, notably the discharge of steam into the atmosphere. One disadvantage which it is impossible to remove is the location of the boiler adjoining the apartment for passengers, who are thus incommoded by smoke fumes, hot air and exhaust steam for the cylinders. If it were not for these points the system would be well applicable not only to suburban tramways but also to short feeders of trunk lines.

The use of fireless, or stored steam, locomotives has not increased sensibly during the last two years. The results from operation by these are not particularly favorable. The system is especially adapted for the suburbs of large cities. The Dodge motor (termed also the Kinetic motor) properly belongs to this class. It is being tried on several lines in America and, as compared with other motors of the same category, presents the advantages of great simplicity of construction and ability to carry in the motor car itself sixty passengers. While the system may be improved, it promises success.

The extension of the compressed air system has made little progress in Europe during the last two years, although it has certain conspicuous advantages. On the other hand this system is being considered favorably in America, and an effort is being made to test its value on a considerable scale. The use of compressed air motors would be preferable to steam motors if they could be run as economically.

The cable system should not be considered as entirely abandoned; on the contrary it has been tried with success in England recently, in spite of the high cost of installation, rapid wear of the cable and loss of power through friction. The system has the advantage of enormous capacity and low operating cost when traffic is extremely heavy.

Gas, benzine and petroleum motors have been improved considerably during the last few years, and the recent gas locomotives merit particular attention because with a greater tractive power they are more economical than gas motor cars. This system would be especially suitable for the operation of tramways in small towns as well as for long lines with light traffic, since the installation is simple and not expensive and fuel is easily obtainable. It has not yet been possible to avoid entirely the disagreeable shaking of the cars and the penetration of the gas odors into the passenger compartment. The gasoline motor is still in the experimental stage. Benzine motors have been perfected to a greater extent, but their use on the Wurtemburg State Railways for suburban traffic has not been for a sufficient length of time to determine their practical utility.

Accumulator traction, which might be considered the ideal, is still in the experimental stage, in spite of the good results already obtained. It continues to be a subject of great interest, and has a hopeful future.

The trolley system is the most widely adopted, the most economical, and its status has been most clearly determined. It is mechanically and electrically correct in principles, and from a commercial standpoint has an economy which can never be surpassed by accumulator. The æsthetic objections to its installation are not as great as they were, because the general public is becoming accustomed slowly to the changes which the system effects in the appearance of the streets.

The underground conduit system has made many advances and secured many advocates who believe that it has a field, in spite of its high cost of installation and maintenance.

The mixed system by accumulators and trolley has been adopted in a number of places, and is interesting from a technical and financial standpoint wherever rights to install a trolley wire can be secured.

The mixed trolley and underground conduit system has less to recommend it than the mixed trolley and accumulator system, since the advantages of the underground conduit do not sufficiently compensate for its disadvantages. However, the data as to its use are rather meager. Again, it must not be forgotten that the later introduction on these roads of trolley, accumulator or other cars would render useless the conduit, and, consequently, the cost of its installation would be lost.

The surface contact electric system presents serious difficulties in the way of keeping the contact blocks free from moisture or other short circuiting agents which might prevent successful operation. The progress made in this department, however, gives hope that the system has a certain future.

The third rail system is the least expensive to install of any, and where a railway operates over its own right of way, and particularly for elevated and underground railroads, it has given excellent results in practice, and upon such roads the system will have a wide application.

To say which among all the mechanical systems of traction is the most desirable from an engineering and economical standpoint is of course a very difficult thing to do, as can be easily seen, and the writer states that he would consider himself extremely presumptuous to endeavor to give definite conclusions as to which should be installed in every case. It is necessary to take up each condition individually and weigh carefully all the relative circumstances in construction and operation. When all is said, however, it is undoubtedly true, he concludes, that the overhead trolley system is the one most generally adopted, not only in Europe but America, and it is the most simple, the most economical and the one which has given in practice the best results up to the present time.

Scientific American.
JANUARY 28, 1899.

COMPRESSED AIR TRACTION IN NEW YORK CITY.

The rapidly growing interest in the development of self-propelled vehicles is resulting in a vast amount of experimental work in the effort to produce a satisfactory motor. Among the various forms of motive power that have been tested, compressed air has in the last two years shown very good results. To those who have not kept in touch with the subject, it may be surprising to learn that compressed air motors have been improved to such a degree that, in point of economy, they compare favorably with other and better known motors which of late years have been more in the public eye. During the earlier stages of the development of the steam locomotive, the attention of eminent engineers was directed to compressed air as possessing some excellent features for purposes of mechanical traction, and half a century ago the great Brunel, with characteristic boldness, equipped several miles of what is now the Great Western Railway, in England, with compressed air, building power stations and laying conduits between the rails. It was a failure, as were all the early attempts in this direction, chiefly because in the Great Western experiments, and those of later date, there was a great loss of power due to the unscientific methods of compressing and expanding the air in the compressors and motors. Brunel's system consisted of a pipe or conduit of compressed air laid between the rails and fed from central stations, and pistons, sliding within the pipe, which were attached to the cars by means of a plow in much the same way as the grips on our modern cable cars. The grips passed through a longitudinal slot on the top of the conduit, which was closed by leather strips which opened and closed to allow the passage of the plow. As was to be expected, the leather strips wore out and failed to close the conduit.

In this and in all the later attempts to use compressed air, however, there was a serious loss due to the fact that a large portion of the energy expended in compressing the air was transformed into heat, which subsequently was lost by radiation. Moreover, where the compressed air was utilized in motors, its expansion was accompanied by a reduction of temperature which produced accumulations of ice sufficient to choke the exhaust.

These difficulties have been overcome by better methods of compression (the work being done in successive stages with intermediate cooling) and by reheating the air prior to its introduction into the cylinders of the motor. During the past two or three years careful experimental work has been done in this direction on two of the leading street railways in New York city. On the One Hundred and Twenty-fifth Street line of the Third Avenue Railway Company several motor cars have been running which were constructed under the Hardie patents, and on the Lenox Avenue line of the Metropolitan Street Railway Company a thorough test has been made of the Hoadley & Knight compressed air motors. In both systems the air was carried in storage flasks, and was heated, by passing it through a tank of hot water, before being used in the cylinders. The Hardie motors were of the single expansion and the Hoadley of the compound type; and in the former the cylinders were direct connected to the axles, while the Hoadley cylinders were connected to a countershaft whose pinions engaged a gear wheel on the axle.

The compound system is said to have given the best results, and it has proved so satisfactory that the two companies have been consolidated into what is now known as the International Air Power Company. A large factory is being built adjacent to the present works of the American Air Power Company, and the company is now busy upon the new motors for operating several important cross-town lines in this city. At an early date the Twenty-eighth and Twenty-ninth Street lines will be in operation, and other main arteries of cross-town travel will be similarly equipped as soon as the motors can be built. It is expected ultimately to have the whole of the Metropolitan Company's great system under either electric or compressed air operation; the former being used on the great trunk lines, running north and south on the avenues, and the latter handling the cross-town and branch lines.

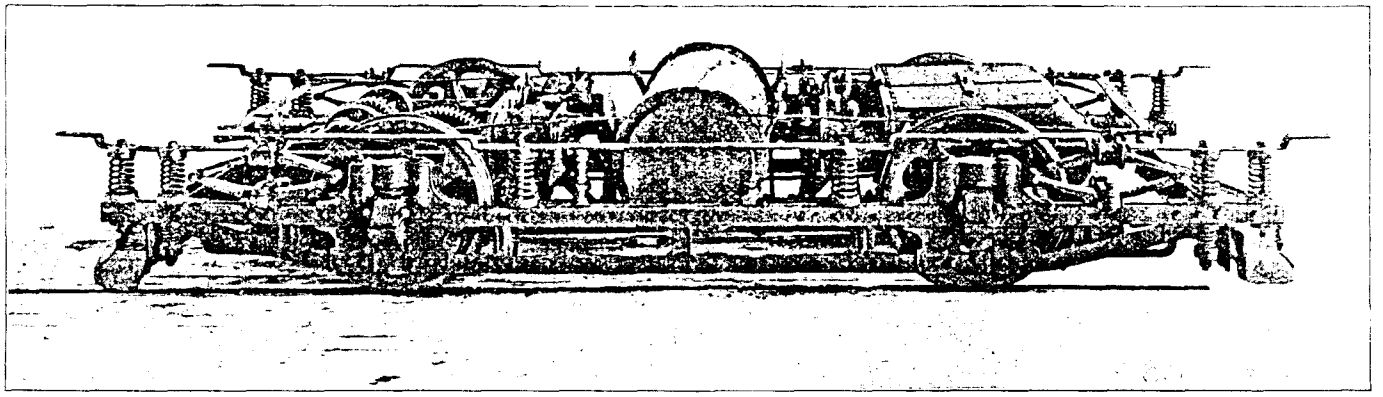
Contemporaneously with the consolidation of the Hardie and Hoadley interests in the International Company comes the announcement of the formation of the New York Autotruck Company, a companion concern to the former. The autotrucks are to use the Hoadley-Knight system, and they will be designed for handling the heavy trucking which is now entirely moved by horses. The press reports speak of the new autotruck as having in active service proved more economical than the horse. This is, we believe, a trifle premature, as the only actual motor thus far constructed is a rather crude affair used for carting material at the works which supply some of the compressing machinery.

As a competitor in the field of automobilism, compressed air will have to prove itself at least the equal of electricity, steam, gas, hot water storage, and other systems before it can hope to fulfill the promise of the promoters that it will remove the horse from the streets of this or any other city. If the motors do as well on the trucks as they have on the street cars, the autotruck may not only replace the horse, but prove to be the coming and abiding type for all forms of automobilism. This, however, has yet to be proved, and if the curiously named vehicles make their appearance on the streets of New York, their performance will be watched with no little interest.

Until, however, an experimental truck has been made and fully tested, and has proved that it can stand the test of actual and continued service in our city streets, it seems premature to expect the public to take very much interest in the extravagant notices which appear in the daily press, stating that a company has been formed with $10,000,000 of capital for exploiting these vehicles. It looks as if the autotruck should and probably will become an actuality, but its serviceableness for the purposes for which it is designed has yet to be proved.

THE HOADLEY-KNIGHT COMPRESSED AIR MOTOR.

In our last issue we gave some account of the development of compressed air traction on the streets of New York city, and drew attention to the fact that experimental and practical work in this direction had been done with two motors, one known as the Hardie motor having been run on several cars on the One Hundred and Twenty-fifth Street line of the Third Avenue Street Railway Company, and the other, built under the Hoadley-Knight patents, having shown good results in operating several cars on the Lenox Avenue branch of the Metropolitan Street Railway Company's system. In the Hardie motor compressed air is used in a single, two-cylinder, high-pressure engine. It is carried in steel reservoirs, located under the seats of the car, and on its way from the reservoir to the motor the air is heated by passing it through a tank of hot water, stored under a pressure of several hundred pounds to the square inch.



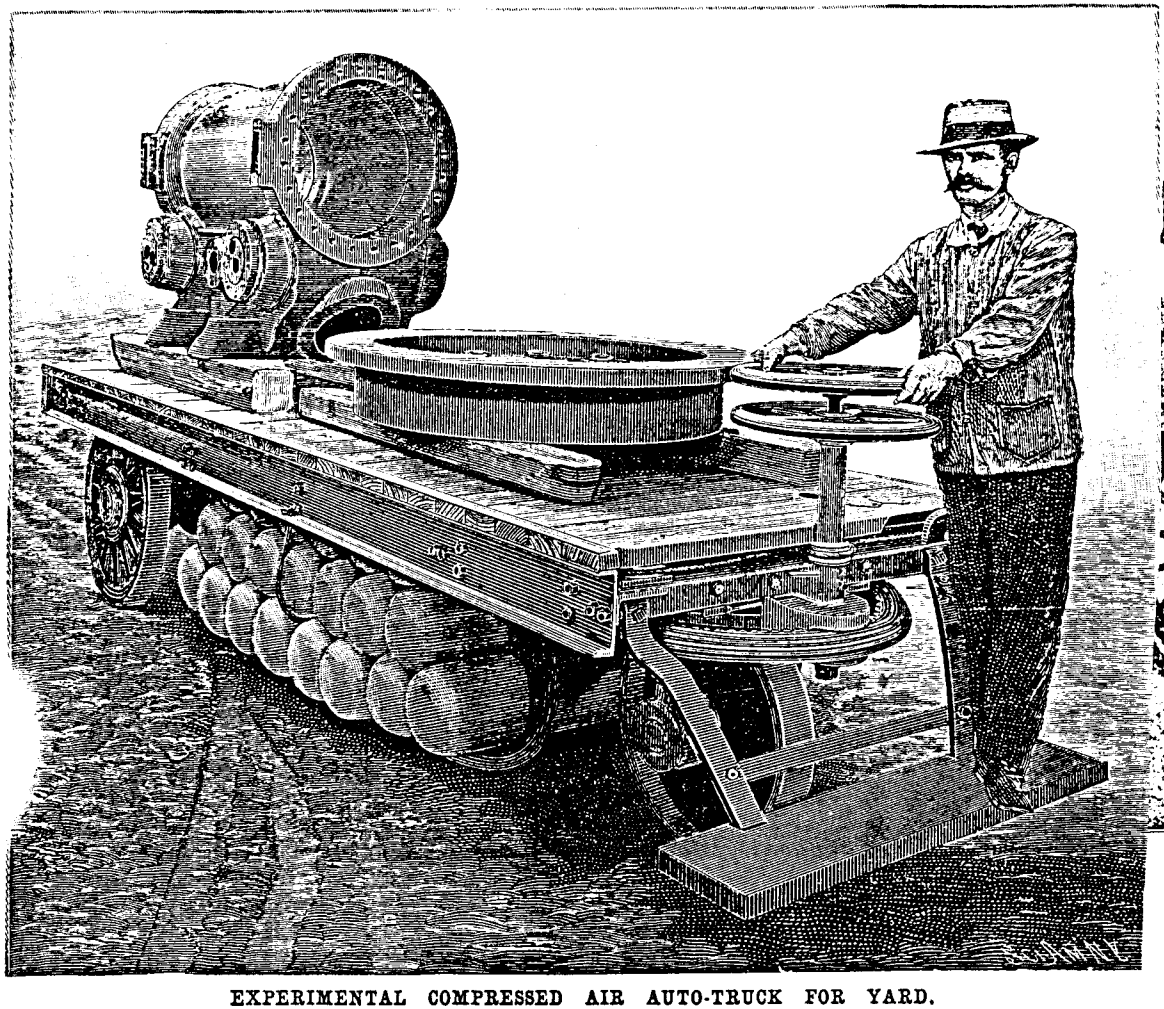
COMPOUND, COMPRESSED AIR MOTOR TRUCK, AS USED ON STREET RAILWAYS.

The Hoadley-Knight motor differs from the Hardie type chiefly in the methods of heating the air and in the fact that the motor is on the compound system. The superior results obtained with the Hoadley type have led to a combination of two companies into the new American Air Power Company, which controls all the patents of both systems, and is now actively engaged in building and supplying the Hoadley-Knight motors for all classes of work.

Our illustrations show a plan view and a photographic reproduction of one of the motors which was successfully at work on the Lenox Avenue line. It will be seen that the truck is of the type ordinarily used for electric cars, and it is one of the advantages of this compressed air motor that it does not involve any structural alterations to the truck to put it in place. The weight of the car when it is equipped is about the same as that of an electric car, the car body weighing 6,500 pounds, the truck 4,500 pounds, the reservoirs 3,600 pounds, the complete motor 3,000 pounds, and the other fittings bringing the total weight of the car up to between 18,000 and 19,000 pounds.

It will be seen from the plans that the power is applied to both axles, the high pressure cylinders driving one axle and the low pressure cylinders the other. The cylinders are, in each case, attached to the outside of a strong, cast-steel casing, which entirely incloses the moving parts of the motors. The lower part of the casings in each case serves to hold a bath of oil, which renders the engine self-lubricating and, because of the close-fitting cover, entirely dust-proof. The high pressure cylinders are 4 inches in diameter, the low pressure cylinders 8 inches, and the common stroke is 6 inches. The crankshaft carries a 9-inch pinion which meshes into a 23-inch gear-wheel on the axle of the car. The hot water tank is placed transversely to the truck and between the cylinders, as shown in the engraving of the complete truck. The supply of compressed air, stored at 2,400 pounds pressure, is carried in a set of cylindrical steel reservoirs, which are placed beneath the seats in the car. From these it is led by a combined throttle and reducing valve, at a pressure of 320 pounds to the square inch, to a coil which is located within the hot water tank, in which the water is under a pressure of between 225 and 300 pounds to the square inch. In passing through the coil the temperature of the air is raised to an extent which greatly increases its capacity. On its way from the coil to the high pressure cylinder a spray of hot water is thrown into the now heated air, in which it is immediately converted into vapor. The combined steam and compressed air then enter the high pressure cylinder. The high pressure exhaust is heated by passing it through the hot water coil, and before the reheated air enters the low pressure cylinders, another spray of hot water is injected into it. The temperature of the air as it issues from the low pressure exhaust is sufficient to prevent any trouble from freezing and choking up the exhaust passages.

The power is controlled by a single lever at either end of the car. When it is thrown over in one direction, the car is propelled at a speed corresponding to the distance through which the lever is moved. When the lever is reversed, the car is stopped, and a further movement in the reverse direction will reverse the motors. With regard to efficiency, it may be said that, in the diagrams showing the work of compression and expansion, the area of the compression cards is 2·015 square inches, and the area of the cards of both high and low pressure cylinders is 1·227 square inches; from which it is seen the compound compressed air motor shows an efficiency of 60·9. It has been found that, owing to certain losses not shown in the diagrams, as a matter of fact, about 35 per cent of the indicated power of the compressors is delivered on the axle of the car in driving the motor. Fifty per cent of this economy is estimated to be due to the reheater, and careful tests have shown that the cost of reheating is about one-fifth the cost of compressing the air. It requires thirty

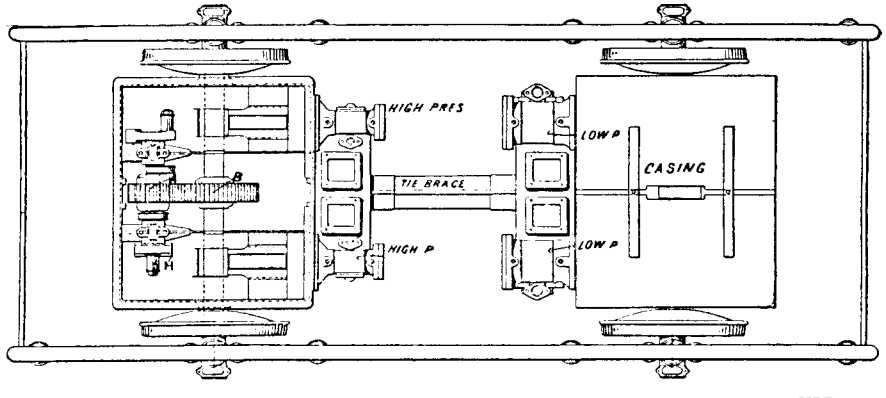


EXPERIMENTAL COMPRESSED AIR AUTO-TRUCK FOR YARD.

to forty pounds of free air to drive a nine-ton twenty-four foot car, and the cost of compressing and reheating the air and of the maintenance of the motor works out as 2·9 cents per car mile.

In view of the large amount of publicity which has been given during the last few weeks to the financial affairs of the motor company and what is known as the auto-truck company, the public would naturally be led to suppose that the auto-truck was in successful service on the streets of our large cities. This is not the case. The only actual compressed air auto-truck in existence as far as we have been able to learn is the crude yard truck shown in the accompanying engraving.

AUTOMOBILE CARRIAGE DRIVEN BY COMPRESSED AIR MOTOR.



PLAN SHOWING ARRANGEMENT OF MOTORS, GEARING, AND CASING.

The Hoadley-Knight motor, it is true, has been applied to an automobile carriage of the kind shown in our engraving, which has the appearance of being a compact and serviceable vehicle; but the auto-truck, so called, exists as yet only upon paper. Plans, however, have been prepared and the company has purchased the Rhode Island Locomotive Works for the purpose of manufacturing cars and motors.

New Interests in Compressed Air as a Motive Power

Late in December and early in January, there were organized several companies with large capital, intending to use compressed air for various purposes, and in view of the financial standing and importance of the interests involved in this movement to place upon the market a new motive power, it is advisable to explain the status of the parent and affiliated companies.

The American Air Power Company, of New York, was organized in January, 1898, as a consolidation of the American Air Power Company, of New Jersey, the General Compressed Air Company, of New Jersey, and the Compressed Air Power Company, of New York. The first two companies had been engaged in developing the Hardie motor, and the third the Hoadley-Knight motor. The capital stock of the consolidation company was $7,000,000, and A. A. McLeod, formerly president of the Reading Railroad system, became the company's president.

In January, 1899, the International Air Power Company, of New Jersey, was formed with a capital of $7,000,000. Later on it was announced that this company had secured from the American Air Power Company exclusive rights for all its letters patent in foreign countries; rights for all patents in North and South America, except those bearing directly upon street railway traction, were reserved by the American Air Power Company. The principal stockholders of the International Air Power Company are said to include some of the strongest and best known street railway and other capitalists in America.

Following the organization of this second company is that of the New York Auto Truck Company for $10,000,000, and the Chicago Auto Truck Company, while a similar company for Philadelphia is to be organized. The International Air Power Company will retain large holdings of stock in these three companies and in others which will be formed in different cities, and will manufacture and sell to them complete compressed air trucks intended to do a general city trucking business, replacing and gradually driving from the field the present horse trucks.

The directors of the New York Auto Truck Company are J. H. Hoadley, Richard Croker, ex-Senator Arthur P. Gorman, Robert McKinstry, Nathan Strauss and Lewis Nixon, owner of the Crescent Shipyards, of Elizabethport, and designer of the United States battle ships Massachusetts, Indiana and Oregon. The directors of the Chicago Auto Truck Company will include Joseph Leiter and associates.

The International Air Power Company has purchased for manufacturing purposes the works of the American Wheelock Engine Company, in Worcester, and the Rhode Island Locomotive Works, in Providence. The new auto trucks will be built at the company's Providence works, and air compressors for the auto truck business in Worcester.

The American Air Power Company is now equipping with compressed air motors and apparatus tweny cars for the Metropolitan Street Railway Company's Twenty-eighth and Twenty-ninth Streets crosstown line, and the Ingersoll Sargent Company has practically completed a four-stage compressor to furnish the necessary motive power. The compressed air power station for the Twenty-eighth and Twenty-ninth Streets line is located at the foot of West Twenty-fourth Street, and work is going on rapidly upon the engine foundations, boilers, etc., while in a small temporary shop near by, the motors are constructed.

A full description of the Hoadley-Knight motors of the American Air Power Company and of the engineering features of the four stage compression was given in the STREET RAILWAY JOURNAL for August, 1897, page 487.

A 1,500-HP. FOUR-STAGE AIR COMPRESSOR.

We illustrate herewith an unusually large air compressor recently installed for the American Air Power Co. by the Ingersoll-Sergeant Drill Co. at the former's power station, 24th St. and the North River, New York city.

Aside from the fact that this compressor will be used to furnish air to operate the most extensive compressed air street railway system in the world, the compressor is of interest because it is perhaps the largest of its class ever built.

A general view of the engine and compressor is given in Fig. 1, which, however, hardly does justice to the size of the machine. Fig. 2 shows the general details of the engine and compressor and the arrangement of the piping, intercoolers, etc.

The engine proper was built by the E. P. Allis Co., of Milwaukee, Wis., and, as will be seen in the illustrations, is a vertical cross-compound condensing engine. It is practically the same as the standard Allis pumping engine, has the usual Reynolds valve motion and embodies no novel features, except, perhaps, the governing mechanism which is connected to the air storage reservoir. This arrangement regulates the speed at which the engine runs to suit the demands of the service until the limiting speed of 75 revolutions per minute is reached, when the automatic engine governor comes into play and prevents any further increase in speed. The feature is, however, common to pumping engines used for water-works.

The engine stands 32 ft. above the level of the engine room floor, which is even with the top of the massive brick foundation. This foundation is in turn 29½ ft. high to give room for the air compressing cylinders, so that the total height from the ground level to the top of the engine cylinder is 59½ ft. At the base of the foundation the overall dimensions are 29 x 33 ft. Running through the center of the foundation is an opening or tunnel 7 ft. wide and 22 ft. high, in which are hung the air cylinders. The engine flywheel is between the high and low-pressure sides of the engine and is 22 ft. in diameter with a rim 2 ft. wide and 18 ins. thick.

The steam cylinders are double acting, 32 and 60 ins. in diameter with a 60-in. stroke. Mounted on brackets close up to the cylinders is a reheating receiver. Steam is supplied at 150 lbs. pressure by four Babcock & Wilcox 250-HP. boilers. The engine speed can be varied from 40 to 75 revolutions by the air governor, as already stated. At 40 revolutions the nominal horse power is 1,000 and at 60 revolutions it runs up to 1,500 HP.

The main steam pipe, Fig. 2, is 12 ins. in diameter, and the exhaust pipe, which is 22 ins. in diameter, is provided with a suitable valve for throwing the exhaust into the condenser, or in case of accident or emergency into the air.

The air and circulating pumps were also furnished by the E. P. Allis Co., the former being a 32 x 12-in. vertical pump with the usual type of surface condenser.

The compressor part of the equipment is worthy of special attention, owing to the amount of air compressed and the high pressure attained. The four cylinders composing this part are arranged tandem below the engine shaft and directly in line with the steam cylinders. The low-

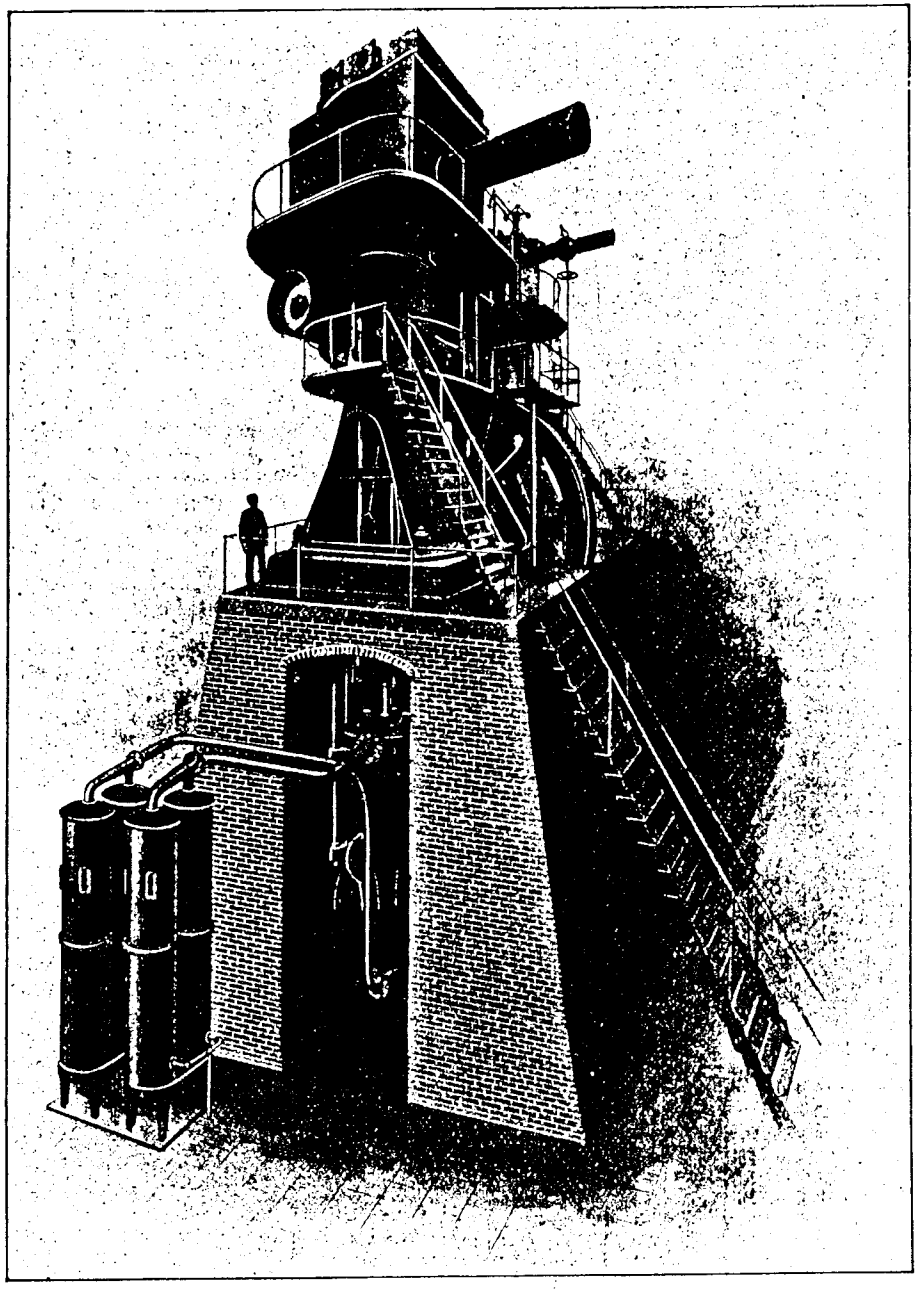


FIG. 1.—PERSPECTIVE VIEW OF A 1,500-HP. AIR COMPRESSOR.
American Air Power Co., New York City.

Engine built by E. P. Allis Co., Milwaukee, Wis.; Compressor by the Ingersoll-Sergeant Drill Co., New York City.

pressure and first intermediate air cylinders are under the low-pressure steam cylinder, while the second intermediate and high-pressure are in the same position under the high-pressure steam cylinder. The heavy air cylinder piston rods end in substantial cast square cross heads, from the corners of which four steel rods extend up inside the engine frame through suitable guide bearings to the engine cross head.

The cylinders are all single-acting, compression occurring in the low and second intermediate cylinders on the up-stroke, and in the first intermediate and high pressure cylinders on the down-stroke. The cylinders have the following dimensions: Low-pressure, 46 ins.; first-intermediate, 24 ins.; second-intermediate, 14 ins.; and the high-pressure, 6 ins.; the stroke in all cases being 60 ins.

Water jackets are provided for the cylinders and the air after each compression is conveyed by heavy copper pipes from the cylinder to a suitable vertical surface intercooler placed outside the engine foundation, as shown in Fig. 2. The pressure in each intercooler and the aftercooler is, of course, the maximum of the respective cylinder, and is in each case as follows: First intercooler, 40 lbs.; second, 180 lbs.; third, 850 lbs.; and in the aftercooler between 2,500 and 2,600 lbs.

The free air capacity of the compressor per stroke is 56.735 cu. ft., which at 40 revolutions per minute gives a free air capacity of 2,269.4 cu. ft. per minute, and this is increased to 3,404.1 cu. ft., with a speed of 60 revolutions per minute. In other words, roughly speaking, this compressor will furnish between 14 and 21 cu. ft. of air per minute at 2,500 lbs. pressure. As this may not be sufficient at all times to supply the cars directly, a storage reservoir has been provided, consisting of a large number of steel bottles, made of a special nickel steel. These will safely withstand a pressure several times greater than that used in service. From this reservoir air will be taken as needed to charge the reservoirs on the street cars.

We are indebted to the Ingersoll-Sergeant Drill Co. for the material from which this description and the illustrations have been prepared.

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COMPRESSED-AIR CARS are suggested for certain lines in Chicago, and the Compressed Air Motor Co., of Chicago, is operating a car on the North Clark St. cable line, as a substitute for the horse cars which are run after midnight, when the cable plant is shut down for inspection. The company is also building an air-motor truck for use on a 60-ft. passenger car, suitable for suburban survice on steam railways. This car is to be tried on one of the railways leading out of Chicago. It will have sufficient storage capacity for a round trip of 25 miles at the average speed of suburban trains, hauling one extra passenger car as a trailer. The mechanism is on the Hardie system, which, as applied to an experimental locomotive for the New York elevated railway, was described in our issue of June 24, 1897. Particulars of service of street cars on this system, in New York, were given in our issue of Oct. 7, 1897.

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Compressed Air Cars for New York

The Metropolitan Street Railway Company is making preparations to run several of its crosstown lines by compressed air, notably, the Twenty-eighth and Twenty-ninth Streets line, between the North and East Rivers. Aside from the motive power, the compressed air cars have a number of interesting features of construction, and in their framing are entirely novel. They were built by the J. G. Brill Company, of Philadelphia.

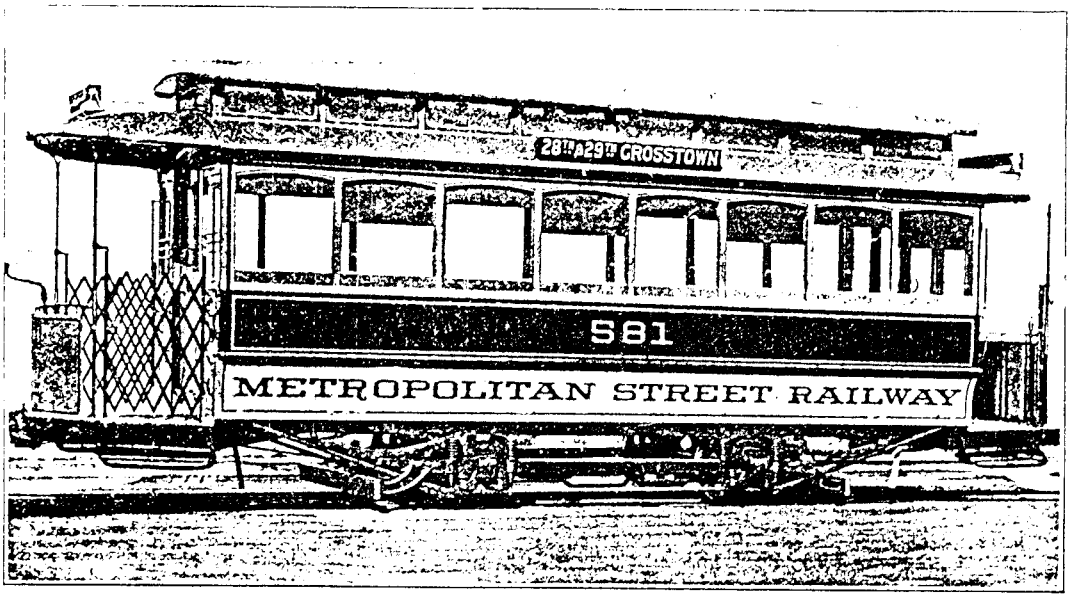
The crosstown lines in New York City below the Harlem River are mostly short, and the traffic, except at the most crowded hours of the day, is composed largely of short rides. The type of car, therefore, to accommodate this business differs materially from that needed in any other part of the city. With compressed air as a motive power, certain changes become necessary in construction, and the result is the car shown in the accompanying engraving. The body is 22 ft. 4 ins. long. The car over the buffers measures 31 ft. 5 ins. It is 6 ft. 6 ins. wide at the sills, and 7 ft. 6 ins. wide at the posts. The platforms, which are not inclosed, are but 4 ft. long. The car stands 27¾ ins. high to the sills, giving a step 14 ins. from the head of the rail. With a low platform, this gives a 12-in. riser. The car is mounted on a No. 21-E truck, and has an 8-ft. wheel base and 30-in. wheels. The gage is standard, 4 ft. 8½ ins.

The whole center of the truck is left open to receive machinery, etc. Three compressed air cylinders, each 9½ ins. in diameter, are to be placed under both of the longitudinal seats, with which the car is fitted. The great wheel base is not a disadvantage of any importance, since these crosstown lines have a very large proportion of tangent. Some of the lines, indeed, are perfectly straight, with the exception of the curves at the switches near the ends of the lines. This feature, of course, makes the long wheel base very advantageous, in fact, because, even with a long body, the car is very steady.

The floor framing of these cars introduces a number of special features. It consists, first, of two side sills of wood, into which two end sills are mortised in the usual way. The side sills are then plated with iron on both sides. The inside plating is turned up at the ends against the end sills, and takes a firm bearing on them. A heavy plate is also put on the outside of the end sills, completely covering the ends of the side sills also. There are in all eight crossings, or cross sills, as they are sometimes termed. Six of these are of angle iron. The two nearest the ends of the car are deep plates turned up against the side sills and bolted fast. All the other crossings are of angle iron carried by malleable iron brackets, which are bolted to both angles and side sills. This form of construction gives an enormous amount of strength and stiffness. In order, however, to obtain good fastenings for the floor and for such attachments as must be necessarily connected to the bottom of the car, each one of these angle iron crossings has a 3-in. "nailing" piece attached to it, and held in place at each end by another malleable angle. These "nailing" pieces are also properly bolted to the angles. The usual diagonal struts are introduced at the ends of the car to keep the frame square.

It will be seen that in this form of construction the wood has been used where its strength can be employed to best advantage, and the metal is introduced in places where wood has naturally its greatest weakness, namely, at the joints. It must be understood that the side sills are only mortised for the timbers at the two ends, thus the whole strength of the wood is preserved. The car body, being very long and having a great overhang, requires an unusual amount of strength to support the long ends, and this strong floor frame was designed to give the required strength.

The springs under these cars were designed to give a very easy motion. The semi-elliptics were made 36 ins. long, not only giving ample support, but making galloping entirely impossible. The side bars of the truck, being under great strain, were made accordingly heavy and stiff, to carry the weight of a heavy car body and the propelling machinery.



COMPRESSED AIR CAR, NEW YORK

There are four folding gates, with solid iron hood supports. The body of the car is, in general, finished according to the Metropolitan standard, the woodwork being selected white ash, and the veneer seat covered with standard Broadway carpet. The ceiling is of three-ply maple, without decoration. The trim inside is all of bronze, and the sash have metal styles. The brakes are of the Sterling pattern.

Each of the posts are provided with a push-button for signalling the conductor, and the lighting is done by three Pintsch gas lamps. The body is supported by a deep gas-pipe truss, well anchored at each end of the sills.

STREET RAILWAY JOURNAL.

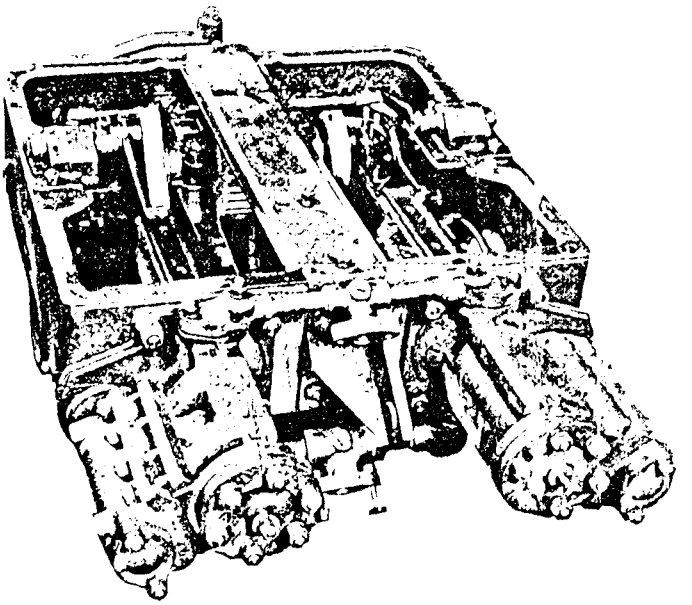
JUNE, 1899.

The electric system has monopolized the attention of street railway engineers for so many years, and its advantages have been so thoroughly demonstrated, that the claims of other powers during the last decade have received scant attention. The latest claimant for a hearing to demonstrate its ability to compete with the electric system, however, is compressed air—latest, not because trials in this power were not made before or concurrently with the electric system, but because the use of compressed air under high pressures as now being tried in this country is entirely new in the history of its application to railway service. Mechanically, the air power motor has been most carefully designed and it is our opinion that if the system should become a successful competitor of the electric for street railway use, it will be upon the general lines described elsewhere in this issue. It is needless to say, however, that some time must yet elapse before absolute figures as to the cost of operation in regular conditions of service on a large enough scale to make this comparable with electric railway service, can be secured. In many respects the system is an attractive one, but it remains to be seen whether there may not be troubles which are not now apparent, but which may militate strongly against its employment.

Compressed Air Motors in New York

It is well known that compressed air motors are in use abroad on several railways, and in the last issue of the STREET RAILWAY JOURNAL some particulars were given of the cost per car mile during 1898 of the motor cars of the Mekarski Compressed Air system upon the line of the General Omnibus Company at Paris. Owing to the development of the trolley system in this country, but little effort has been made up to the present time to give the compressed air system a thorough trial in this country, although a few cars on the Mekarski system were operated several years ago in Toledo, Westfield and other cities.

The possibility of developing some system which would operate without overhead wires, however, induced certain prominent capitalists interested in the street railways of New York to look into compressed air as a motive power about three years ago, and to determine whether it might be made a substitute for the underground conduit electric system and trolley. The preliminary steps taken by this syndicate, which resulted in the construction of an air motor equipment for street cars upon lines entirely different from those which had been followed abroad, are familiar to the readers of the STREET RAILWAY JOURNAL, through an article published in these columns in August, 1897, which described the system as then constructed and in use on the Lenox Avenue and Columbus Avenue divisions of the Metropolitan Street Railway Company. Since the publication of that article, the American Air Power Company has been organized, and has acquired all the stock, patents and property of the General Compressed Air Company, the American Air Power Company, of New Jersey, and the Compressed Air Company of New York. This company has been organized with A. A. McLeod as president, Henry A. Humley as secretary and treasurer, and W. H. Knight, engineer, and the following board of directors: A. A. McLeod, W. L. Elkins, Thomas Dolan, Thomas F. Ryan and J. H. Hoadley.

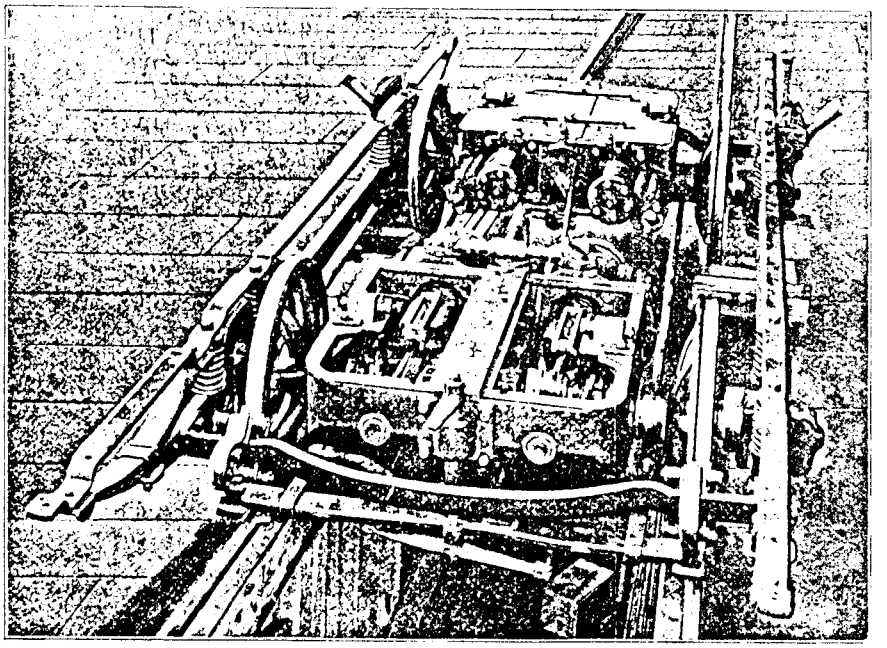


TOP VIEW OF AIR MOTOR

In the meantime, also, important improvements have been introduced in the mechanical features of the system, so that now the company claims an economy of operation closely approximating, if not less than that of the overhead trolley. To determine the actual operating expenses, however, the American Air Power Company has made arrangements with the Metropolitan Street Railway Company to introduce the system on an extensive scale in the equipment of the Twenty-eighth and Twenty-ninth Street lines of the latter company. These lines are now being relaid with 9-in. girder rail to afford substantial construction for the cars.

In the meantime, the company has built an extensive compressing plant at the western terminal of the Twenty-eighth and Twenty-ninth Streets lines at West Twenty-fourth Street and Twelfth Avenue, containing a 1000 h.p.

direct driven, four-stage compressor, with charging outfit and car house to accommodate the equipment necessary for the operation of the Twenty-eighth and Twenty-ninth Streets lines. The capacity of this compressor is eighty cars, and it will operate the Thirty-fourth Street and other cross-town lines as far down town as Bleecker Street. During the completion of the large compressor ten air power cars are performing night service on the Twenty-third Street crosstown line in regular passenger service.



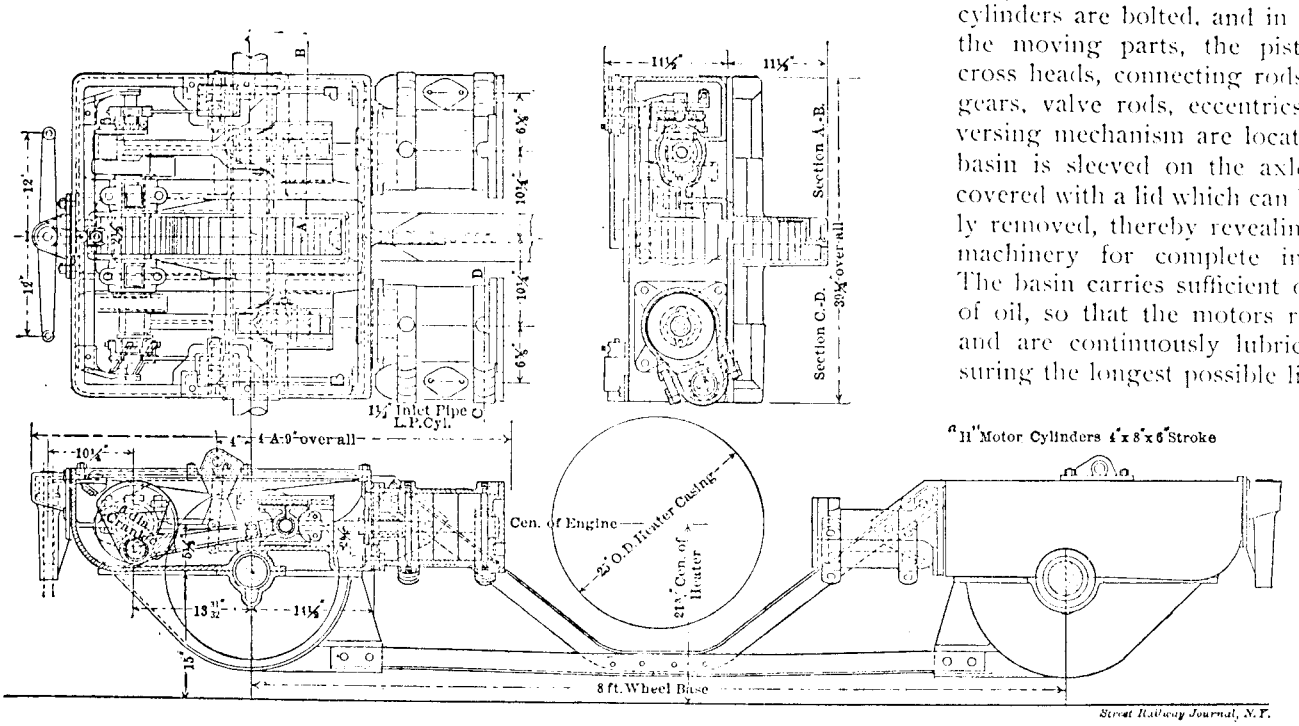
VIEW OF AIR MOTOR TRUCK

The cars do not differ in exterior appearance in any way from the ordinary underground conduit cars in use on that line. The car body is the same in every particular, and is mounted on a 21 E Brill truck, which carries the air motors. The latter are completely enclosed in a dust-proof case, in which they revolve in oil, lubricating themselves continuously without the attention of an operator. The use of side rods is completely dispensed with, as each axle is driven independently, one by two high-pressure motors, the other by two low-pressure motors. In fact, the principle closely followed in the design of the equipment was to follow the general standard street railway practice as developed on electric roads, the purpose being to retain the use of the standard wheels, axles, trucks and car bodies, as it was thought that these have now reached a form where the expense of maintenance was a minimum.

The controller is designed with two handles, one for direction, the other for speed, with duplicate controllers at each end of the car, making it easy for a motorman familiar with an electric power to operate one propelled by compressed air.

The air power system as in use now in New York may be described in detail as follows:

On each axle is mounted an iron clad motor having two cylinders and cranks at right angles. One motor has two high pressure cylinders 4 ins. in diameter and 6-in. stroke. The other motor has two low pressure cylinders 8 ins. in diameter and 6-in. stroke. Upon the crank shaft of these motors is a pinion about 9¼ ins. in diameter, meshing into a 21-in. gear wheel mounted on the middle of the axle. The axle is straight as used for electric motor cars, and the wheels are ordinary street car wheels. The motor consists essentially of a cast iron case or basin, to which the two cylinders are bolted, and in which all the moving parts, the piston rods, cross heads, connecting rods, cranks, gears, valve rods, eccentrics and reversing mechanism are located. The basin is sleeved on the axle, and is covered with a lid which can be quickly removed, thereby revealing all the machinery for complete inspection. The basin carries sufficient quantities of oil, so that the motors run in oil and are continuously lubricated, insuring the longest possible life.



PLAN AND CROSS AND LONGITUDINAL SECTIONS OF AIR MOTOR

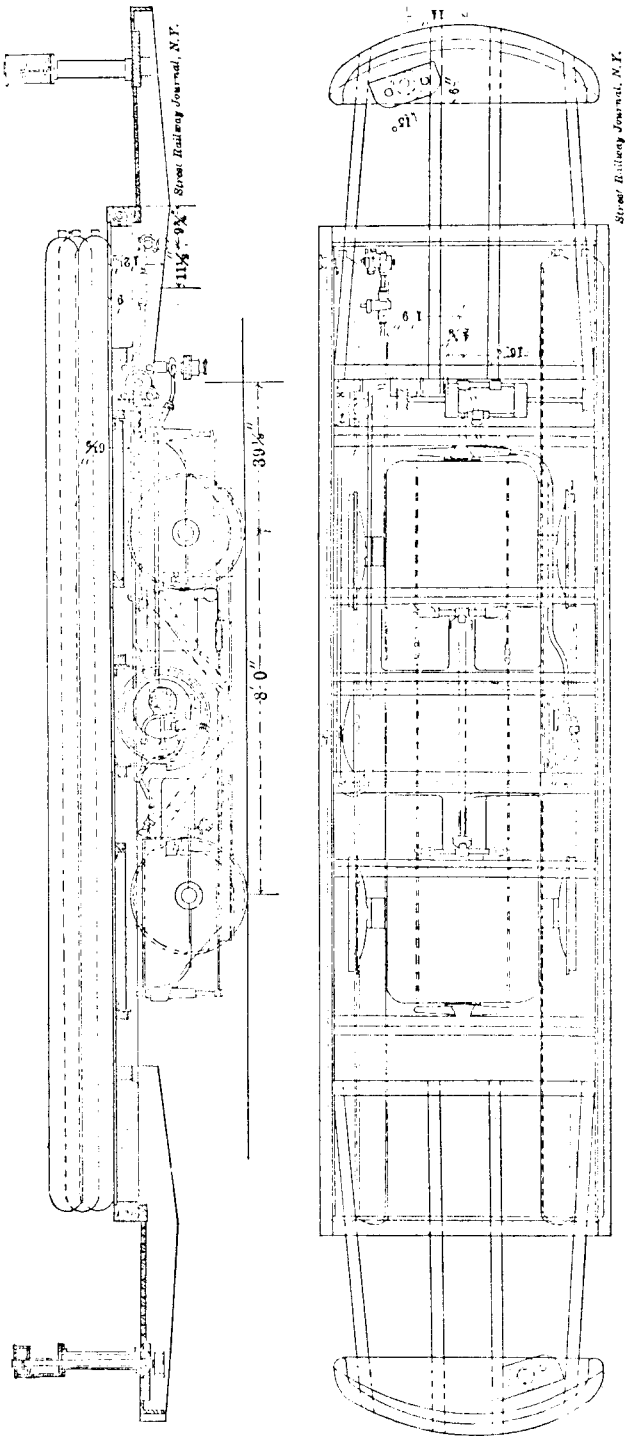
The air reservoirs, which are seamless steel bottles, are carried under the seats. These flasks measure 21 ft. 6 ins. in length and 2 ft. 5 ins. in circumference outside. There are six on each car. They weigh about 700 lbs. each, and are 9 millimeters thick, and are tested to three times the pressure they are intended to carry. From these pipes a 1 in. pipe leads to a reducing valve, which reduces the storage pressure to the working pressure. Before reaching the reducing valve, the pipe passes for about 2½ ft. from its length through the heater, so that it can receive sufficient heat to prevent the subsequent freezing of any moisture which may be in it.

The heater consists of a wrought iron reservoir, that is supported on the cross pieces which connect the two motors, and is charged with hot water under a pressure of about 210 lbs., which corresponds to a temperature of 400 degs. The capacity of the heater is about 60 cu. ft.

After passing through the heater, where it takes up heat, as described, the air enters the reducing valve, which is of the ordinary type, where its pressure is reduced from 2400 lbs., which is that in the reservoirs, to 320 lbs. From the reducing valve it branches and flows to the throttle valves, one at each end of the car. From the throttle valves it passes to the injector, shown on page 375, where a certain amount of moisture is given to the air. This injector is fed from the heater, and consequently the water is at the same temperature as that in the heater, viz., 400 degs. The moisture not taken up by the air falls to the bottom of the injector chamber, and is led back to the heater. From the injector the air passes through a spiral coil in the heater, consisting of a 1-in. pipe having a linear length of about 50 ft. In this passage it is brought up to the temperature in the heater, so that in the next step, when it is admitted to the high-pressure cylinder, it has a temperature of 400 degs. After exhausting from the high-pressure cylinder, it is carried through a connection underneath the heater to the low-pressure cylinder, and is then exhausted into the atmosphere on the lower side of the low-pressure cylinder through a muffler. By having one motor high pressure and the other low pressure, undue slipping of the wheels is prevented, as when the high-pressure wheels slip the low-pressure motor gets more air and more pressure. On the other hand, when the low-pressure slips its wheel it draws down the pressure in the exhaust of the high-pressure cylinder, correspondingly increasing the strength of the high-pressure motor.

The direction of the flow of the air is shown diagrammatically in the cut below, in which *A* is the charging valve through which the air passes through the head *B* to the bottles, and *B* to the reducing valve *D*. The throttle valves are shown at *E*, the injector at *F*, the connection to the high pressure cylinders at *G* and the connection to the low pressure cylinder at *O*.

In its use of a heater, the practice of the American Air Power Company is similar to that of practically all the other manufacturers of air motors, but, as will be seen, the form of heater adopted is quite different from that which has been used elsewhere. The object of imparting moisture to the air is two-fold; first, it assists in packing the joints, thereby reducing the leakage, as the air would be excessively dry owing to the high temperature to which it is brought. Another advantage of adding the moisture is that during the expansion in the cylinders the water keeps flashing into steam all along the passage as the piston advances beyond the point of cut off. This keeps up the pressure toward the end of the stroke and gives an almost isothermal expansion instead of adiabatic expansion.



PLAN AND SIDE ELEVATION OF EQUIPMENT

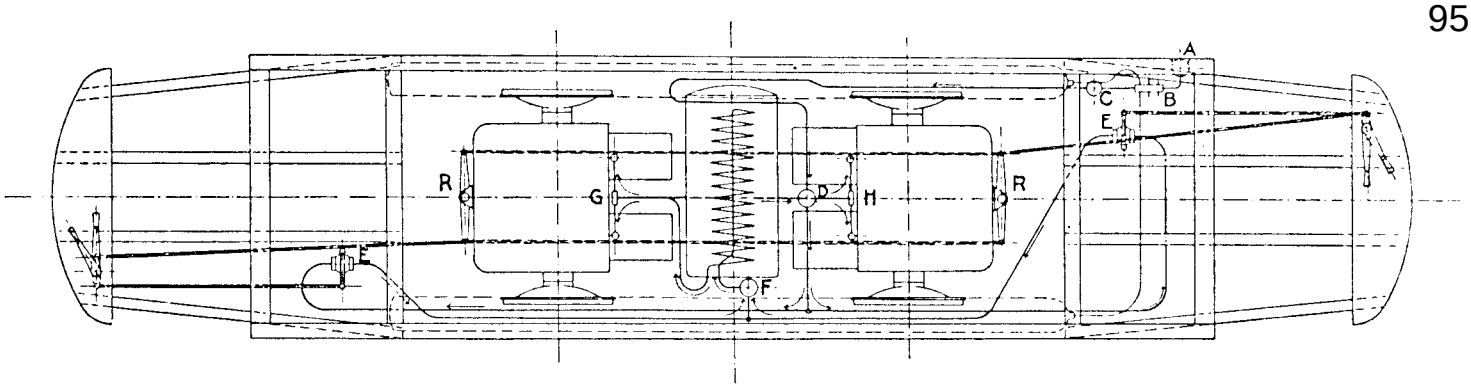
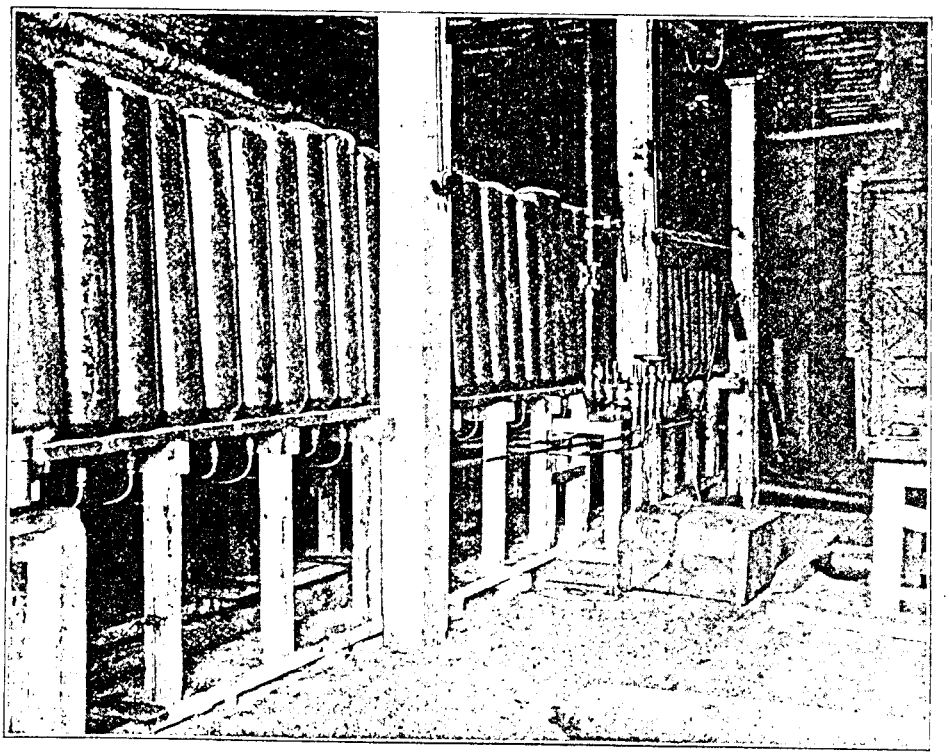


DIAGRAM SHOWING DIRECTION OF AIR

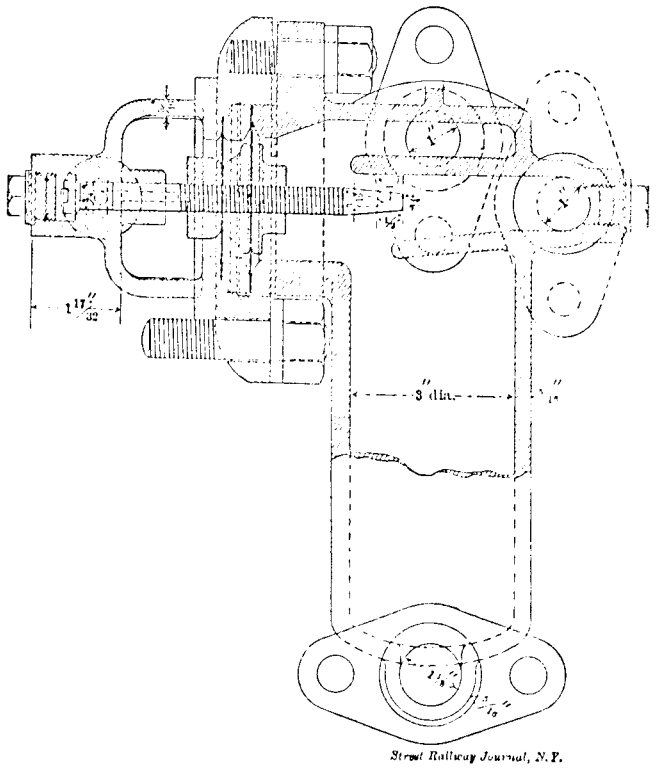
In the heater used on the Mekarski system, to which reference has already been made, the air is made to pass through the hot water; this system was not adopted, first, because the experimental tests conducted with it seemed to indicate that its use was liable to bring excessive quantities of water over into the motors, and secondly, to reduce the pressure in the heater from that of the air to the 210 lbs. required to maintain the temperature of the water at 400 degs. As will be seen from the sectional view of the injector, the amount of moisture injected into the air can be regulated, while the necessary amount of heat is imparted to the air through its dry passage through the heater.

Two methods of control are adopted, one by varying the cut off, and the other by the use of a throttle. Both methods of control are operated from the platform, which is equipped with a double handle controller, the upper handle being that moving the throttle and the lower that adjusting the cut off. The latter handle has four notches, corresponding to stop, and three degrees of speed. On the first notch the valve is set to cut off at one-quarter stroke, the second stop at one-third stroke, and the third notch at five-eighths the length of the stroke. At the neutral position the air pressure is entirely cut off, and as the motor cylinders are fitted with check valves, the car can coast without creating any back pressure or vacuum. The usual position of the cut off when the car is in operation is that of the first, or one-quarter, notch, which is, of course, the most economical point of running. The speed is then controlled by the throttle. Should the motorman desire more power or higher speed than can be given with the throttle open, the cut off can be advanced to one-third or five-eighths point, and to avoid accident the motors can be reversed if necessary, by throwing the cut off controlling handle around to the reversing position without touching the throttle, although this brings a strain upon the motors similar to that experienced by electric motors when suddenly reversed. No special notches are provided on the reversing side of the cut off controller disc, as they would be little used. When the car reaches the terminal of its route, the two controller handles are lifted off the spindle and carried to the other end of the car, as with electric operation.

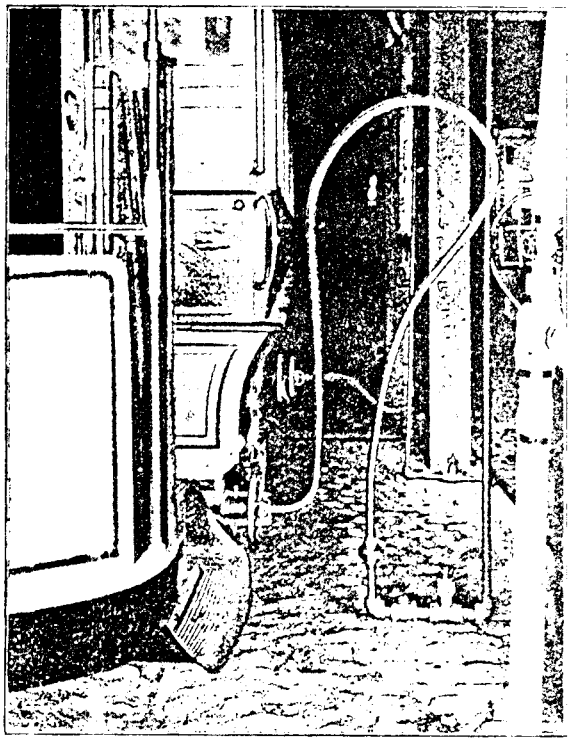
The results secured during the past two years have demonstrated that the motors are highly efficient and exceedingly durable, all the original parts being still in use. The manufacturers estimate that making a liberal allowance for the wear which must occur, and which, in the case of the more rapidly wearing parts has been measured, the maintenance per car mile will compare favorably with that of an electrical equipment.



VIEW IN STORAGE ROOM



SECTION OF INJECTOR



METHOD OF CHARGING CARS

The weight of the standard car as in use on the Twenty-eighth and Twenty-ninth Streets lines is as follows:

Car body	6000 lbs.
Trucks	4500 "
Air reservoirs	4200 "
Heater	700 "
Motors (each 1400 lbs.)	2800 "
Controlling apparatus and other fittings	400 "
Piping	150 "
Total	18,750 lbs.

The motors upon which this estimate is based are capable of slipping the wheels on a dry rail under a weight of 30,000 lbs., corresponding to that of a powerful electric motor equipment, with which, as will be seen, it does not differ materially in weight.

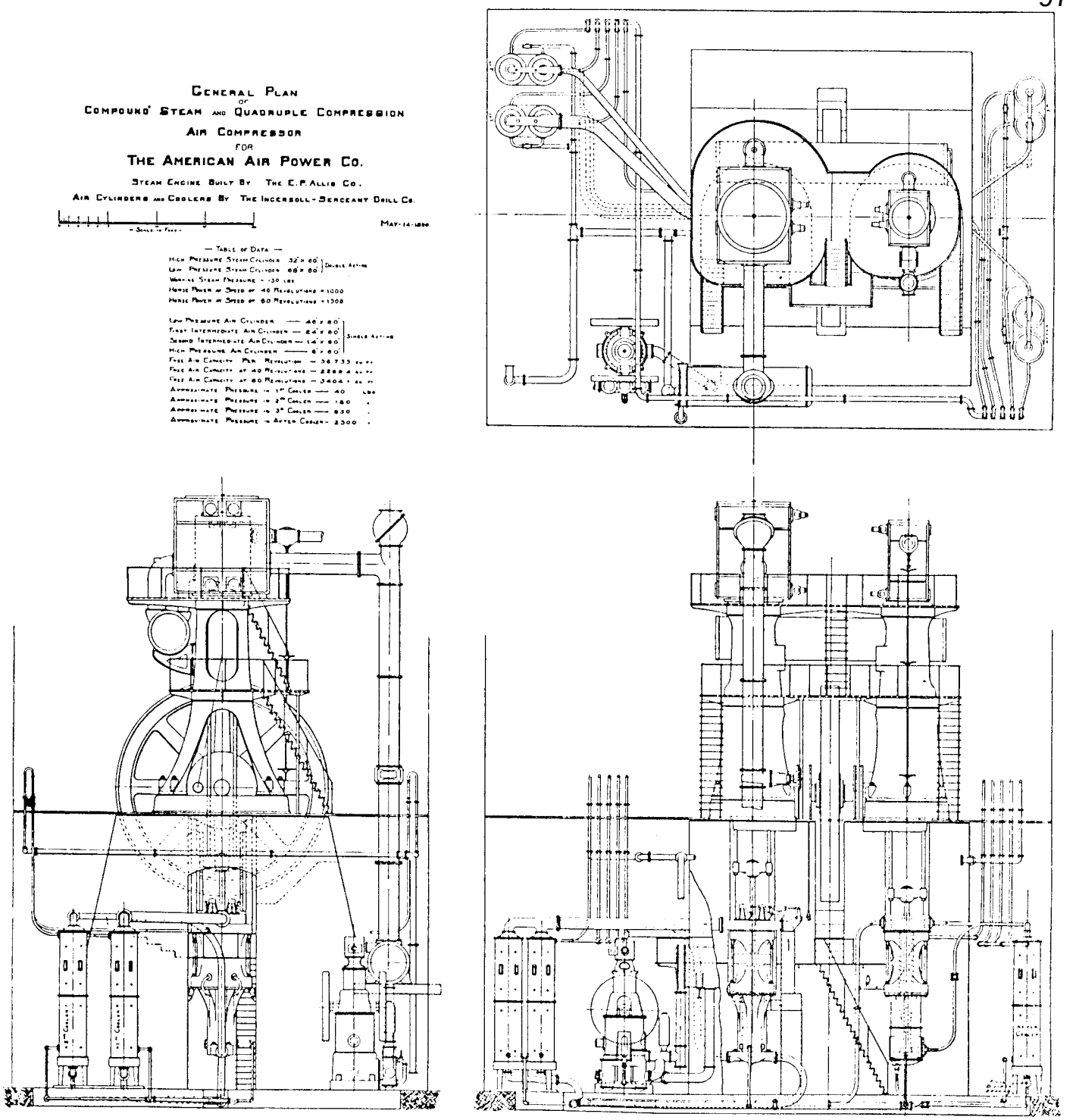
Several sample indicator diagrams, taken from the high and low pressure cylinders, are given on page 378. As will be noticed, they are similar to locomotive diagrams, and have the characteristics of diagrams taken from cylinders with link type of cut off.

Reviewing briefly now the motor equipment, it will be seen that the system differs in many respects from that used abroad, notably (*a*), in the form of motors employed, (*b*) in the method of heating, and (*c*) in the high pressure used. The adoption of a pressure of 2400 lbs. in the reservoirs was to increase their capacity. As at present designed, the cars can run 15 miles on a trip with a charge that is restricted to a space under the seats, and this can be increased to 20, 30 or 40 miles by crowding in all the flasks that the space would allow, or by increasing the pressure, as the company is now preparing to do. As the reservoirs have a capacity for withstanding three times the pressure used in them, it will be readily seen that the element of danger is practically eliminated. There is no deteriorating influence on the reservoirs incident to the use of this pressure, nor has there been any explosion with any of the flasks by air except when premeditated, and only then with the greatest difficulty and with apparatus specially constructed to bring the required force into play.

The cars operate noticably without noise, and start noticeably without jar and with a cushioned effect which is extremely easy for passengers.

The method of charging is another feature to which the engineers of the company have devoted a great deal of attention, and which is now accomplished in a minimum space of time. A general view of the main charging room is shown on page 375. The main charging reservoir consists of a large number of the same type of flasks as used on the car, but carried in a rack and piped to a manifold, from which the air from the compressor is switched into any bank of reservoirs desired. From this point the air under pressure is piped to the charging room, where are located the charging nozzles. The latter are carried upon a flexible goose neck so arranged that the nozzles can be readily fitted to the charging valve. Adjoining the air charging nozzle, but located in such a position that it will come opposite to the heater, is the hot water charging nozzle, which is similar in general appearance to that used for charging the air reservoirs. This device has a double set of pipes, one for introducing the hot water into the reservoir, and the other to allow the discharge of the water which may be in the heater after a run. The process of charging the air reservoir, hot water reservoir and removing the cooled water can be accomplished simultaneously and in a short space of time.

The compressor plant, which has just been completed at the corner of Twelfth Avenue and Twenty-fourth Street, by the Ingersoll-Sergent Drill Company, is unusual in almost all of its features, but especially in two points, its


General Plan
of
Compound Steam and Quadruple Compression
Air Compressor
for
The American Air Power Co.
Steam Engine Built By The E. P. Allis Co.
Air Cylinders and Coolers By The Ingersoll-Sergeant Drill Co.
May 14 1899
— Table of Data —
High Pressure Steam Cylinder 32" x 60"
Low Pressure Steam Cylinder 68" x 60"
Double Acting
Working Steam Pressure - 150 lbs
Horse Power at Speed of 40 Revolutions = 1000
Horse Power at Speed of 60 Revolutions = 1500
Low Pressure Air Cylinder — 46" x 60"
First Intermediate Air Cylinder — 24" x 60"
Second Intermediate Air Cylinder — 14" x 60"
High Pressure Air Cylinder — 6" x 60"
Single Acting
Free Air Capacity Per Revolution — 36.733 cu. ft.
Free Air Capacity at 40 Revolutions — 2268.4 cu. ft.
Free Air Capacity at 60 Revolutions — 3402.1 cu. ft.
Approximate Pressure in 1st Cooler — 40 lbs
Approximate Pressure in 2nd Cooler — 180 "
Approximate Pressure in 3rd Cooler — 830 "
Approximate Pressure in After Cooler — 2300 "

GENERAL PLAN AND SIDE ELEVATIONS OF LARGE COMPRESSOR

great power and the high pressure obtained. High pressures with smaller machines are common, but pressures of 2400 lbs. to the square inch in 1000-h.p. machines are essentially unique.

In general the machine consists of a vertical cross compound engine, built by the E. P. Allis Company, of Milwaukee, which has cylinders 32 ins. and 68 ins. x 60 ins. stroke, and is provided with Reynolds Corliss valve gear. With steam pressure of 150 lbs., furnished by Babcock & Wilcox boilers, 40 r.p.m., and most economical point of cut off, the horse power is 1000. The shaft is of hammered iron 22 ins. in diameter outside of the journals and 20 ins. diameter in the bearings which are 36 ins. long. The fly wheel, placed between the cylinders, is 22 ft. in diameter and weighs 60 tons. The engine is mounted upon brick piers, and directly underneath it is placed the air compressor.

This machine is of the four-cylinder type, the low pressure cylinder being 46 ins., the first intermediate 24 ins., the second intermediate 14 ins., and the high pressure

cylinder 6 ins. in diameter. The stroke being common with that of the engine is 60 ins. All of these cylinders are single acting and are water-jacketed. The free air capacity per revolution is 56.735 cu. ft.; capacity at 40 r.p.m., 2269.4 cu. ft., and the free air capacity at 60 r.p.m. is 3404.1 cu. ft. The approximate pressures in the different coolers are given in the large diagram showing cycle of operation.

The compressor pistons are arranged in pairs vertically in line beneath the steam cylinders as is shown in side and end elevations. The initial and first intermediate air cylinder being below the low pressure steam cylinder, while the second intermediate and high pressure air cylinders are below the high pressure steam cylinder. Motion is transmitted from the steam engine cross heads through distance rods, one pair for each crosshead, to a crosshead attached to the air cylinder piston rods.

The intercoolers employed are of two different designs The two for the lower pressures consist each of a shell inclosing a nest of vertically arranged cooling pipes, through which the air passes going from one cylinder to the other. The coolers for the higher pressures consist each of a shell inclosing a pipe coil. The former construction was adopted for the lower pressures because great cooling surface was required on account of the large volume of air, but in dealing with the higher pressures coils were substituted so as to dispense with as many joints as possible. The coolers are arranged so that in case of leakage of air from the cooling pipes into the shell or casing this air will rise with the circulating water up to the operating floor of the engine room and discharge through a slight discharge pipe under the immediate care of the engineer. All the piping from the first air cylinder and through the entire compressing plant is of copper.

What may be called an auxiliary governor controlled by air pressure is provided to act upon the governor of the steam engine. This consists of a weighted lever which is operated upon by a small piston, which in turn is actuated by the air pressure. If for any reason the pressure should become excessive, the lever is lifted. This opens a valve admitting air to a device on the governor, so designed as to reduce the steam supply and for all practical purposes, to throttle the engine.

Some idea of the massiveness of the machine may be obtained from the bare statement that it is 60 ft. in height. It will be employed exclusively for supplying air to the air motor cars on the street railway cars.

The water used for cooling the air in the intercoolers is taken from the North River, which is a few hundred feet from the station, through a 16 in. water main. After passing through the intercoolers this water is discharged into the river through a second 16-in. main.

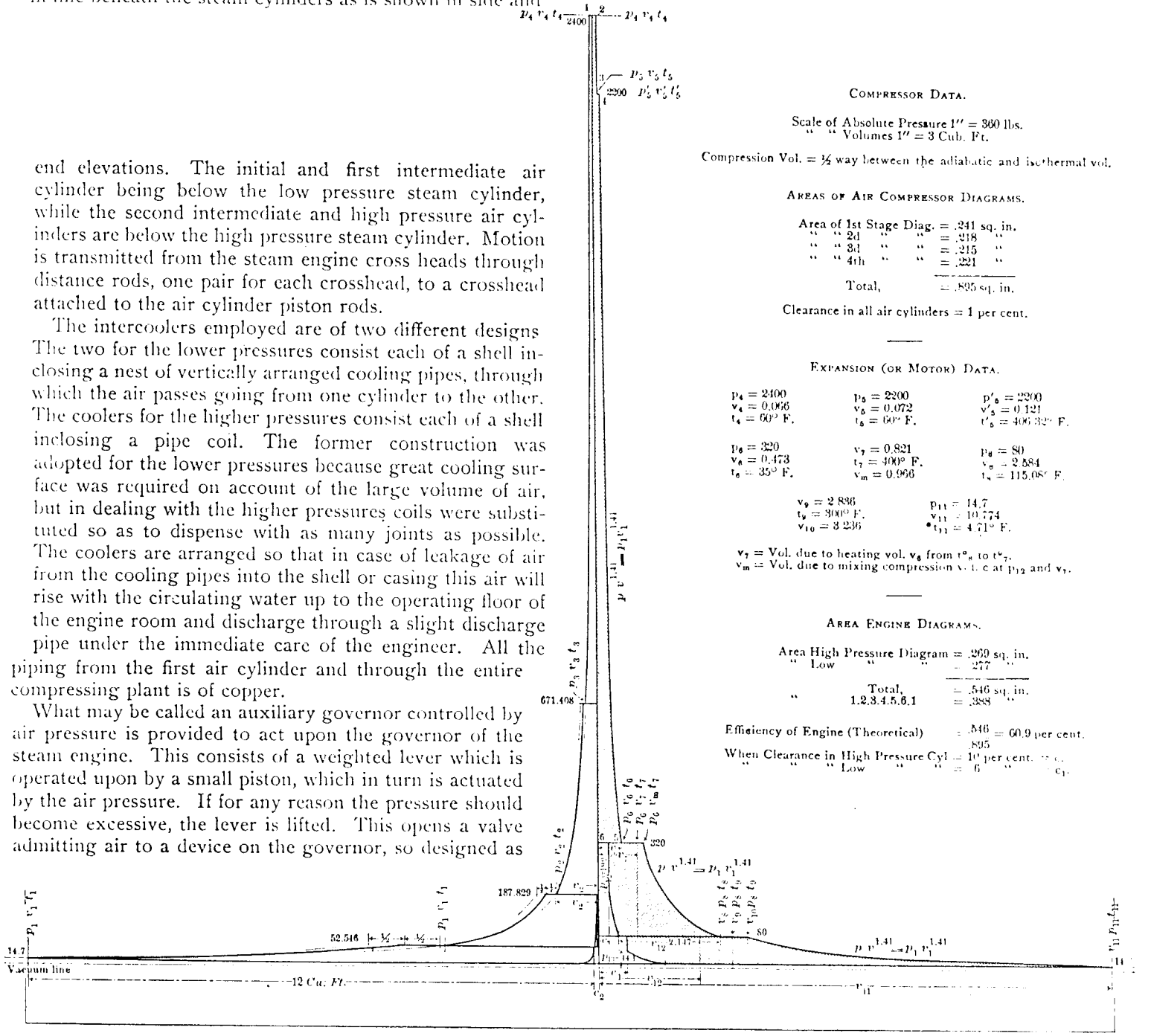
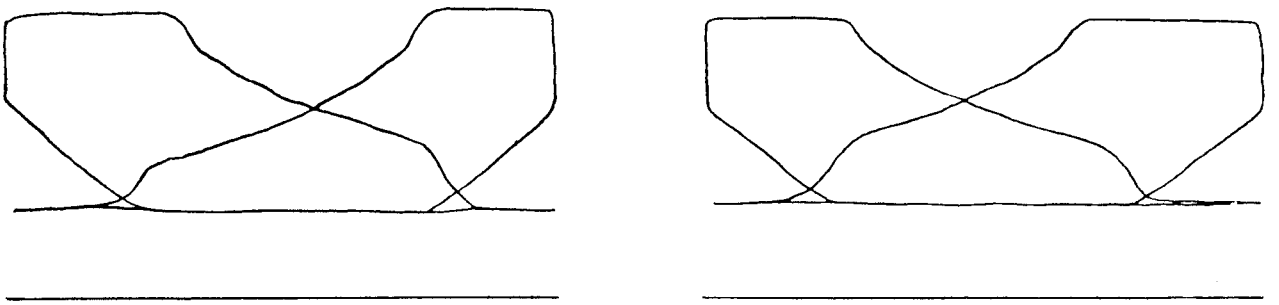

Compressor Data.
Scale of Absolute Pressure 1" = 360 lbs.
" " Volumes 1" = 3 Cub. Ft.
Compression Vol. = ¼ way between the adiabatic and isothermal vol.
Areas of Air Compressor Diagrams.
Area of 1st Stage Diag. = .241 sq. in.
" " 2d " " = .218 "
" " 3d " " = .215 "
" " 4th " " = .221 "
Total, = .895 sq. in.
Clearance in all air cylinders = 1 per cent.
Expansion (or Motor) Data.
$p_4 = 2400$ $v_4 = 0.066$ $t_4 = 60°$ F.
$p_5 = 2200$ $v_5 = 0.072$ $t_5 = 60°$ F.
$p'_5 = 2200$ $v'_5 = 0.121$ $t'_5 = 406.32°$ F.
$p_6 = 320$ $v_6 = 0.473$ $t_6 = 35°$ F.
$v_7 = 0.821$ $t_7 = 400°$ F. $v_m = 0.966$
$p_8 = 80$ $v_8 = 2.884$ $t_8 = 115.08°$ F.
$v_9 = 2.836$ $t_9 = 300°$ F. $v_{10} = 3.236$
$p_{11} = 14.7$ $v_{11} = 10.774$ $t_{11} = 47.1°$ F.
v_7 = Vol. due to heating vol. v_6 from $t°_6$ to $t°_7$.
v_m = Vol. due to mixing compression v. i. c at p_{12} and v_7.
Area Engine Diagrams.
Area High Pressure Diagram = .269 sq. in.
" Low " " = .277 "
" Total, 1.2.3.4.5.6.1 = .546 sq. in.
= .388 "
Efficiency of Engine (Theoretical) = .846 = 60.9 per cent.
When Clearance in High Pressure Cyl = 10 per cent. c_2.
" " " Low " " = 6 " " c_1.
2400
2200
671.408
320
187.829
52.546
80
14.7
Vacuum line
12 Cu. Ft.

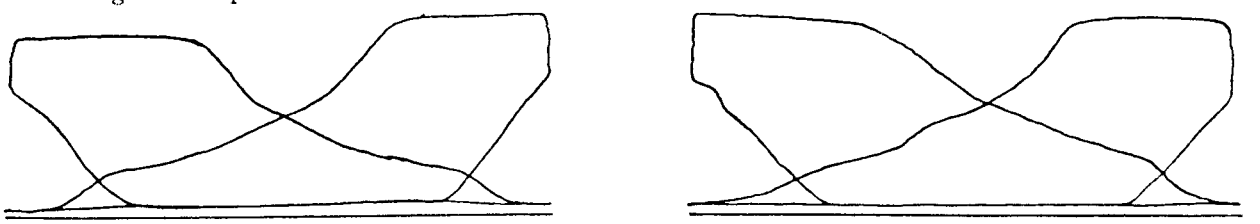
DIAGRAM OF COMPRESSION AND EXPANSION

Referring now particularly to the diagram given on the previous page, showing the cycle of compression and expansion, this diagram is drawn to scale, the abscissæ representing volumes, and the ordinates pressures. The left hand side of the diagram shows the compression curve, and the right hand side the expansion curve. Twelve cubic



SAMPLE INDICATOR DIAGRAMS FROM HIGH PRESSURE CYLINDER OF MOTOR

feet of air is taken as a basis, the scale of pressures being 1 in. to 3 cu. ft. The curve of actual compression in each cylinder of the compressor is considered to be half way between the theoretical adiabatic and isothermal curves on account of the water jacketing, and at the end of each stage of compression the air is brought back to the corresponding point on the isothermal curve through the cooling of the air in the intercoolers. Short arcs of the true isothermal and adiabatic curves are given on the diagram at the end of each stage of compression.



SAMPLE INDICATOR DIAGRAMS FROM LOW PRESSURE CYLINDER OF MOTOR

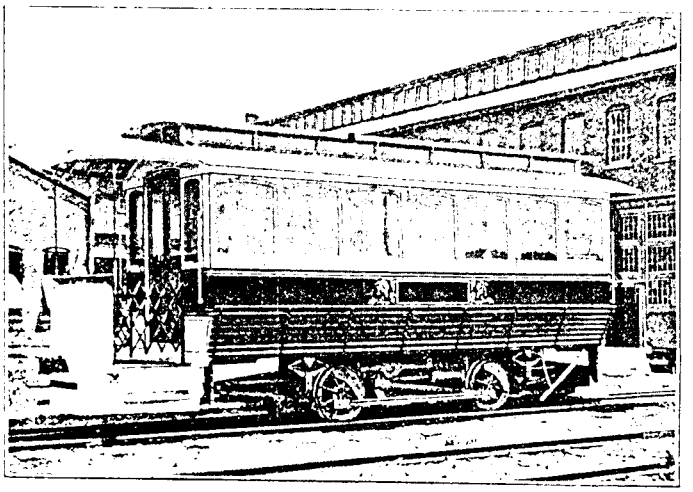
The portion of the curve to the right hand of the center line shows the pressures and volumes at each stage of expansion. The actual values of pressure, volume and temperature at the end of each stage are shown by p_4 v_4 t_4, p_5 v_5 t_5 . . p_m v_m t_m. The effect of heating the air is shown in the differences between v_5 t_5 and v'_5 t'_5, and again between v_6 t_6 and v_7 t_7. The effect of the injection of moisture is shown in the difference between v_7 and v_m.

The theoretical efficiency of the entire mechanical cycle can, of course, be obtained by dividing that portion of the area of the right hand curve, which represents work performed, i. e., that of the high pressure and low pressure diagrams, by the entire area of the left hand curve. According to these figures, the theoretical efficiency of the cycle is 60.9 per cent. This figure, however, is, of course, slightly in excess of the true efficiency of the entire system on account of the addition of heat from the hot water heater. The effect of subtracting this, however, will not materially affect the total efficiency, as given above.

The question of air consumption and cost is, of course, an important one. Upon this point the company hopes to be able to contribute some important data soon. From tests already made, however, Mr. Knight, chief engineer of the company, states that the average consumption per car mile has been 450 cu. ft. of air, and the cost per car mile has been about $.025.

Compressed Air Cars in Chicago

A test is being made of compressed air as a motive power on some cars being operated on the lines of the North Chicago Street Railroad Company. The work is being done under the auspices of the Compressed Air Motor Company, of Chicago. The cars are modeled after those that were operated for a year on 125th Street, in New York, and have all the added improvements suggested by the experience secured with this type of cars in New York. The system employed is known as that of the Hardie, and



COMPRESSED AIR CAR

Robert Hardie, chief engineer of the company, and well known in the field of compressed air development, is in charge of the installation, and superintends the operation of the cars. To bring out the new features, a brief description of the equipment will follow: The cars are 28 ft. long over all, and weigh, when fully equipped, including the truck and mechanism, about 9 tons. The wheels are 26 ins. in diameter, and are coupled after the manner of locomotive practice. The power is supplied from two cylinders, each 7 ins. x 14 ins., mounted one on each side of the truck, from which the piston rod connects with the crosshead, and this is connected to the coupling rod by means of a rocker arm. The valve gear is controlled by a regular Stevenson's link, with a cut off, and is operated by separate eccentrics. A variation of cut-off is effected by the reversing link.

Air brakes are employed for controlling the car, and the brake cylinder is located under one end, near the platform. The controlling handle is located against the dashboard, and in connection with this is a by-pass starting-valve.

The air is stored in reservoirs, which are located under the seat and in other convenient positions on the truck beneath the floor of the car. The tanks under the seats are 9 ins. in diameter, and extend the full length of the car. All these tanks are of seamless tubing, manufactured in Germany by the Mannesmann Company, and bear the marks and guarantee of the inspectors of the German Government, by whom every tank is tested before shipping. The testing pressure is 4800 lbs. to the square inch. The charge for operating the cars is carried at an initial pressure of 2200 lbs. to the square inch, and the tanks included in the equipment have a capacity of 51 cubic feet. The pressure is automatically reduced, however, to 150 lbs. to the square inch, and is then passed through a reheating tank, and is delivered to the cylinders at the latter pressure. The reheating tank consists of a shell of boiler plate, and is 18 ins. in diameter x 7 ft. in length, and when the car is ready for service is reheated by live steam at a temperature of about 300 degs. The air is admitted to a perforated pipe in the bottom of this tank and bubbles up through the water, and in its passage absorbs heat and moisture, which adds to its economical value and prevents the ports from freezing from the excessive low temperature attending the expansion of the charge.

It is interesting to note in this connection the economical feature of reheating the air. From some tests that have been made, it was found that a car with a full charge of cold air was able to make a trip of 8 miles, while with the same charge and the air reheated as above described a total of 15 miles was easily made, a gain of 7 miles having been secured with an estimated expenditure of 10 lbs. of coal, the amount theoretically required for raising the water to the necessary temperature. This estimate is based on the theory that there are about 8000 available heat units to a pound of coal. For starting the car the valves are so arranged that air under increased pressure can be delivered to the cylinders, enabling the cars to start easily and positively under all conditions, without regard to the position of the cut-off valves. As soon as the car is under way the high pressure is cut off, and the cylinders work under a normal pressure of 150 lbs.

In order to provide the necessary pressure for operating the cars two Norwalk three-stage compressors have been installed in the tension room of the Clark Street cable power system, and steam for operating them is taken from the boilers of the station. A nest of twenty reservoirs of the same type as those described for carrying the charge on the car is provided near the compressors. These are arranged in four rows and five tiers, and are divided in two sections of ten each, each section being coupled at one end by means of copper tubing to a single pipe, which is fitted with a valve and operating wheel. These tanks are 22 ft. in length and 9 ins. in diameter. In the process of compressing a charge the air passes through a coil of pipes contained in a large tank filled with water. From this it passes through a condensing device, by means of which the condensation from the moisture in the atmosphere is tapped off, so that only comparatively dry air enters the storage tank.

Mr. Hardie has been experimenting with compressed air as a motive power since 1876, and is now confident that he has brought his system to a commercial success. He states that the only drawback or delay in the introduction of compressed air as a motive power has been the difficulty of getting sufficient capital to demonstrate the system on a large scale. He claims that the compressed air motor has passed through the stages of evolution very much as the electric motor; that while the early types of electric motors were virtually failures in the light of present experience, they have now reached a degree of commercial efficiency, and he believes that with ten years of experience with the compressed air motors, under the same care and interest that has been expended on the electric motor, that the air will have surpassed the latter and become as universally popular. The Compressed Air Motor Company in Chicago was virtually organized four years ago, at the time the experiments were undertaken in the East, but very little has been done, as the company has been awaiting results of experiments made by the Eastern company. The organization of the company is now composed of the following: Henry D. Cooke, president; Alexander C. Soper, treasurer; William E. Selleck, assistant treasurer, with Robert Hardie as chief engineer. W. J. Chalmers, of the firm of Chalmers & Co., engine builders of Chicago, is one of the directors.

Compressed Air Cars in Chicago

The Compressed Air Motor Company, of Illinois, with headquarters at Chicago, reports that it placed in operation on May 30, 1899, one of its compressed air motor cars, replacing one of the horse cars in the night service of the North Clark Street Cable Railway. It is stated that this car has performed a continuous service, carrying passengers each night without failure or delay, and, it is said, entirely with satisfaction to the street railway officials. Since May 30 an additional compressed air car has also been put on, and air cars are now doing the "owl" service between the City Hall and the city limits.

On the first and second trips at night one or two trail cars are attached to the motor car, and in a single round trip of 7 miles 417 passengers have been carried.

SCIENTIFIC AMERICAN

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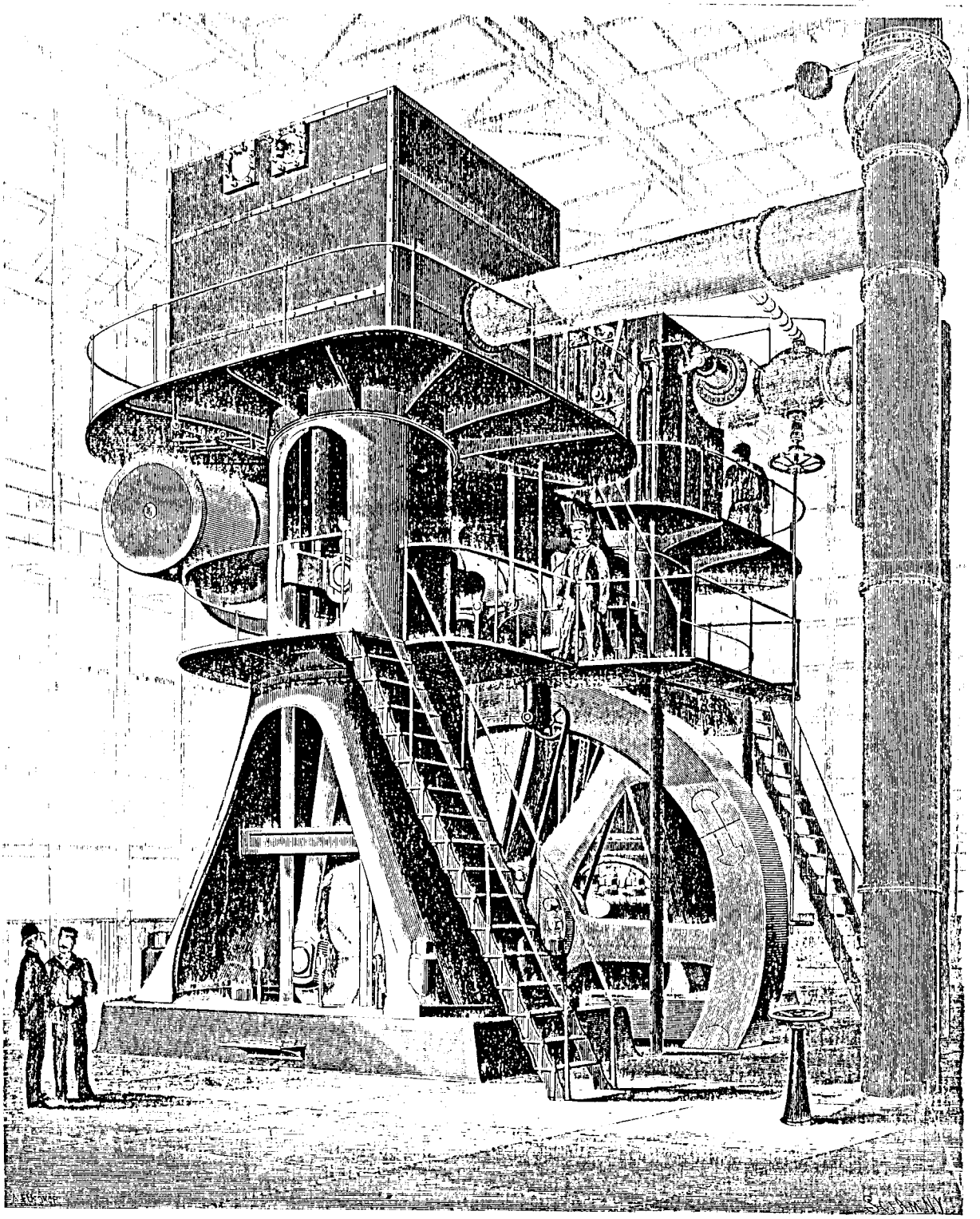


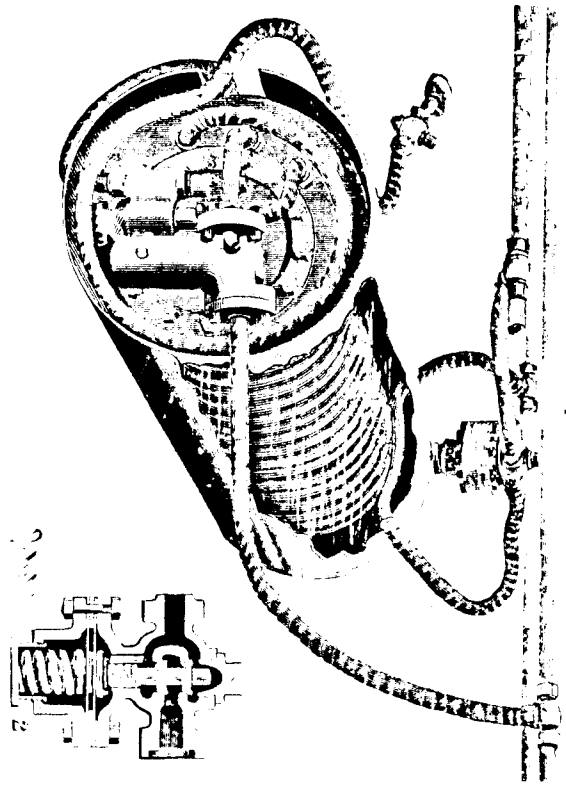
COMPRESSED AIR TRACTION IN NEW YORK CITY—1,000 HORSE POWER COMPRESSING ENGINE.—[See page 184.]

Scientific American.

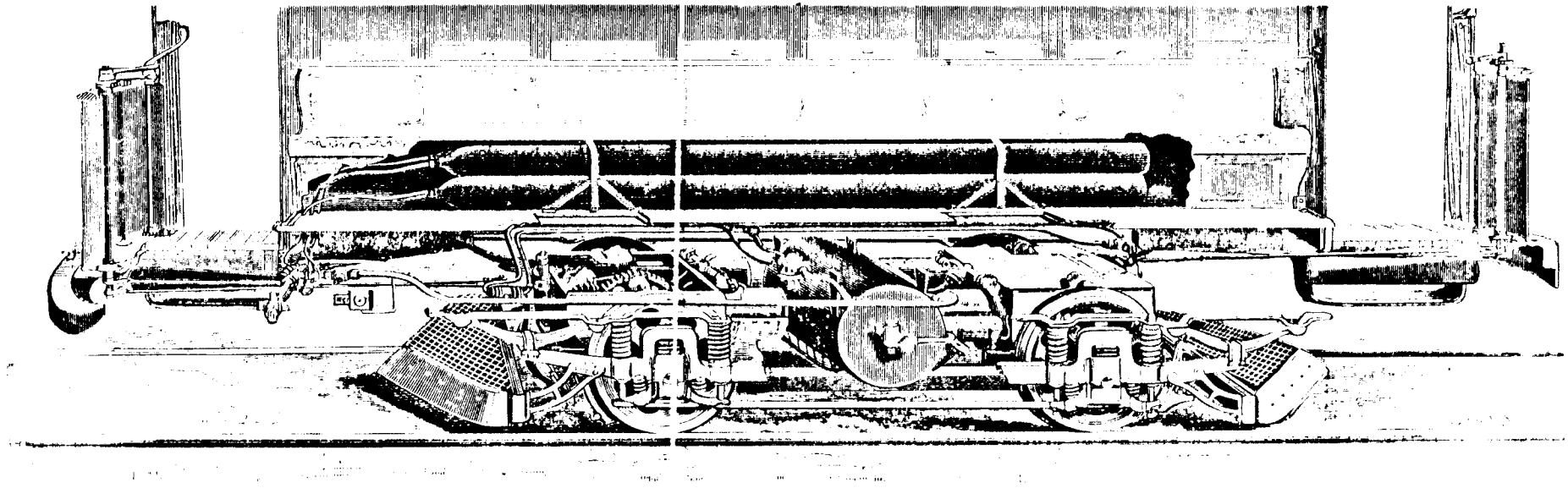
SEPTEMBER 16, 1899.

COMPRESSED AIR TRACTION IN NEW YORK CITY.

The extensive compressed air plant which has recently been erected by the American Air Power Company at the corner of Twelfth Avenue and Twenty-fourth Street, in this city, is now in active operation, and the new compressed air cars which it supplies are in regular service on the Twenty-eighth and Twenty-ninth Street lines of the Metropolitan Street Railway Company. The compressing engine is of special interest, both on account of its abnormal size and power and the high working pressure which is obtained. The single compressing engine is of 1,000 horse power, and the compressed air, after the fourth stage of cooling, is stored in the flasks at the high pressure of 2,400 pounds to the square inch. The engine, which is of the vertical cross-compound type, built by the Allis Company, of Milwaukee, is an extremely handsome specimen of the engine builders' art, and together with its massive brick foundations, it towers 60 feet above the ground floor of the building. Our front page engraving, which is taken at the level of upper floor of the engine house, shows only the engine proper and the upper courses of the massive brick piers on which it is carried. The diagram of the whole plant shows the compressors and the four inter-coolers situated on the ground floor of the building. The compressing engine has cylinders 32 inches and 68 inches in diameter by 60 inches stroke. Steam is furnished at a pressure of 150 pounds to the square inch, and working with the most economical point of cut-off the horse power is just 1,000. Our illustration shows the massive character of the construction, and as an instance of the size of its parts we may mention that the crank shaft is 22 inches in diameter, with bearings 20 inches in diameter by 36 inches in length, while the flywheel, which is placed centrally on the shaft between the cranks, is 22 feet in diameter and weighs 60 tons. The air compressor, which is carried directly beneath, is of the four-cylinder type, the compressing cylinders being securely anchored between the masses of brickwork which form the two legs of the piers. The low pressure cylinder is 46 inches, the intermediates are 24 inches and 14 inches, and the high pressure cylinder 6 inches in diameter, the common stroke, of course, being 60 inches or the same as that of the engine. The initial and first intermediate air cylinders are placed directly below the low pressure steam cylinder, and the second intermediate and high pressure air cylinders are below the high pressure steam cylinders. Each crosshead of the steam engine has four transverse arms, from which four distance rods lead down to connect with the corresponding crosshead to which the air pressure piston rod is attached. These rods are clearly shown on



DETAILS OF THE HEATER AND REDUCING VALVE.

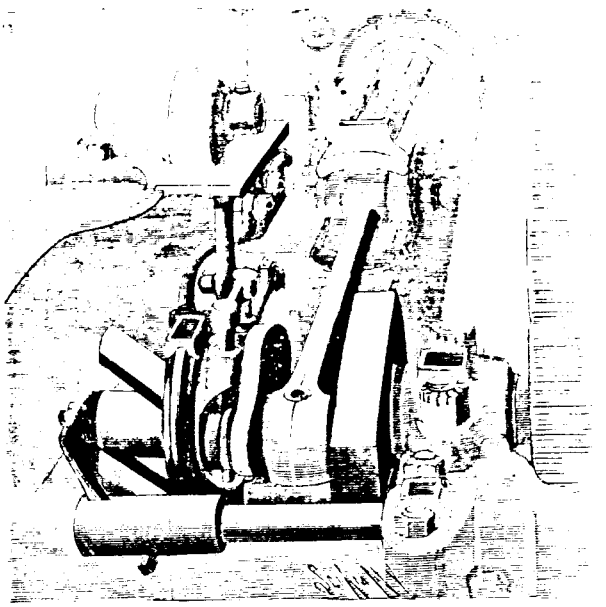


ARRANGEMENT OF STORAGE FLASKS, MOTORS, AND HEATER ON COMPRESSED AIR CARS OF METROPOLITAN STREET RAILWAY COMPANY.

our first page engraving and in the diagram already referred to.

There are four sets of intermediate coolers for reducing the temperature of the air at each stage of compression, placed conveniently on either side of the foundations. Each of the two inter-coolers for the lower pressures consists of a cylindrical shell containing a set of vertical cooling pipes, while in the coolers for the higher pressures a single coil pipe is used; the air in each case passing through the pipes, which are surrounded with circulating water at atmospheric temperature. The action of the system is as follows: The air after compression in the low pressure cylinder is led through the first inter-cooler, from which it issues carrying a pressure of 40 pounds to the square inch. It then passes to the first intermediate cylinder, where, after further compression, it is led to the second inter-cooler which it leaves at a pressure of 180 pounds to the square inch. It is next compressed in the second intermediate cylinder, then cooled to atmospheric temperature at a pressure of 850 pounds, and finally it is compressed in the 6-inch cylinder and cooled to atmospheric temperature under a pressure of 2,400 pounds to the square inch, at which pressure it is led to a nest of storage cylinders in the charging room. The water used for cooling the air in the inter-coolers is taken from the North River, which is only a couple of hundred yards distant, through a 16-inch water main, and after passing through the inter-coolers the water is returned to the river through a discharge main of the same size. Adjoining the engine house is a charging plant and a car house. The cars on their return from a trip are run in on the tracks adjoining the storage cylinders, where suitable connections are made and a fresh supply of compressed air at the working pressure is fed to the storage cylinders, which are carried beneath the seats of the cars.

The cars which are being used in this service are practically the same in construction as the four-wheel cars which are used on the underground trolley lines. The car body weighs 6,000 pounds, the trucks 4,500 pounds, the air reservoirs 4,200 pounds, two motors weigh each 1,400 pounds, and the other parts and fittings of the car bring up the total weight to about 9½ tons. The air motors are carried one upon each axle, in two dustproof cast iron casings. Each axle is driven independently, one of them by the two high pressure motors and the other by the two low pressure motors. It will be thus seen that the cars are made to conform in respect of distribution of the driving power to the standard practice on electrically equipped lines. The high pressure motor has two high pressure cylinders, each 4 inches in diameter with a 6-inch stroke, and similarly the low pressure motor has two cylinders 8 inches in diameter by 6-inch stroke. In each case a 9¼-inch pinion is geared upon the crank shaft and meshes with a 21-inch gear wheel keyed on the middle of the car axle. The cylinders are bolted to the casing and lie outside of the same, while within the casing are the piston rods, crossheads, cranks, gears, and in fact all of the moving mechanism, and the whole is closed in with a cast iron cover, which on being lifted exposes all the moving parts for inspection or repairs. One of our engravings, showing one cylinder and its connections, is introduced to illustrate the construction of the reversing mechanism. The eccentric disk is not mounted directly upon the shaft but upon a pair of parallel guides which are pitched at an angle to the shaft, one above and one below it, and have a motion parallel to its axis. When the guides are thrust in toward the crank the eccentric disk is thrown up, and when they are drawn out the disk is thrown down, thereby giving a forward or reverse motion to the engine. The idea is not new; but it has been ingeniously applied in the present instance, and lends itself admirably to the peculiar construction of these motors. It does away with one eccentric and the usual link motion. The



HALF VIEW OF ONE MOTOR, SHOWING REVERSING GEAR.

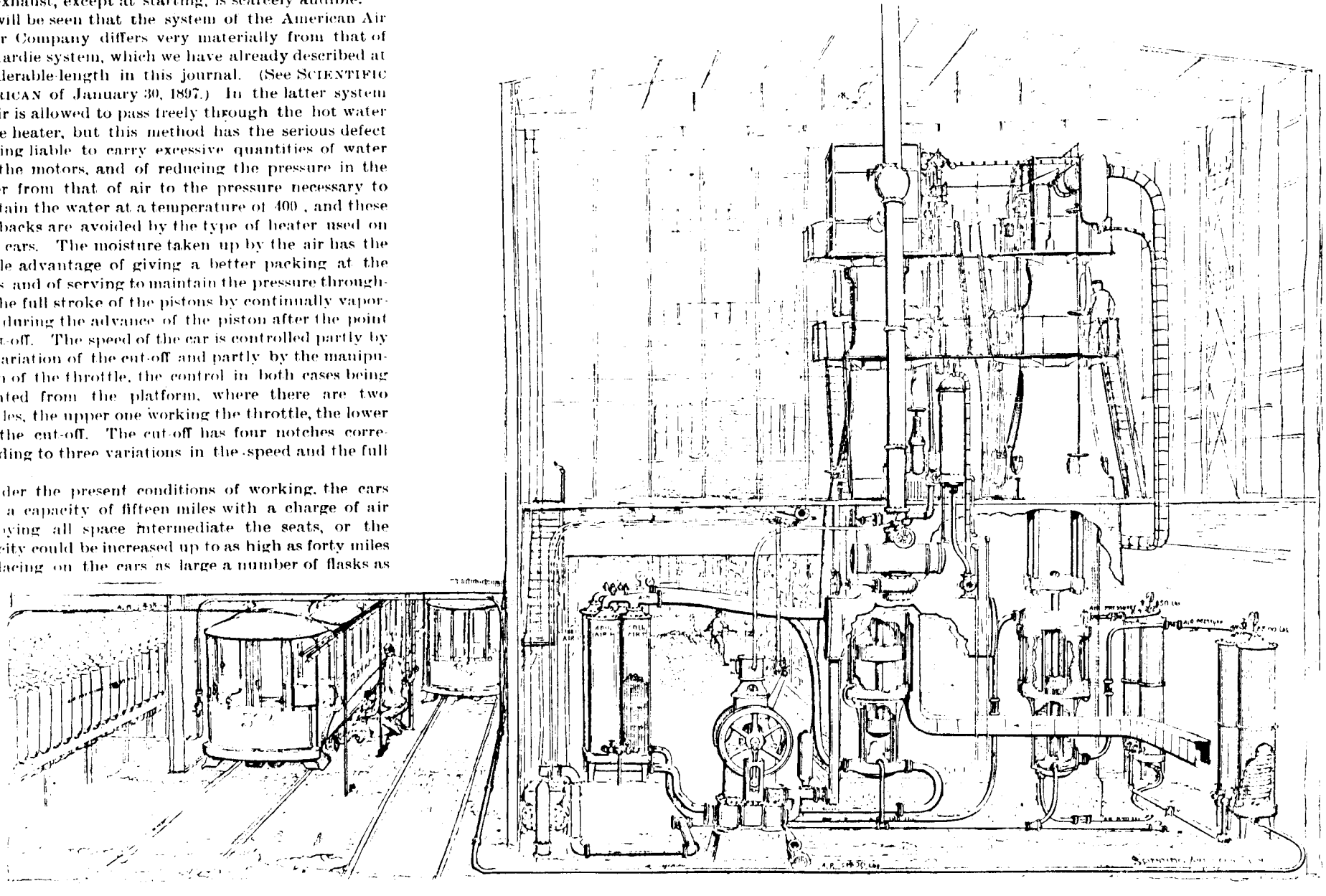
bottom of the casing is filled with oil so that the motors are self-lubricating after the fashion of the Westinghouse and other fast-running engines. The construction is very compact and the whole design well worked out.

The compressed air is carried in seamless steel flasks, which are placed beneath the seats of the car, three on each side, as shown in the accompanying engraving. The flasks are 21½ feet in length by 2 feet 5 inches in external circumference and they are tested, before being placed in service, to a pressure three times as great as the working pressure. From the ends of flasks the air is led through the heater, a wrought iron cylindrical reservoir which is supported between the two motors, as shown in the detail drawings of the car and the heater. The latter is charged with 60 cubic feet of hot water under a pressure of 210 pounds at a temperature of 400 degrees. After the pipe has passed through the heater where the air takes up sufficient heat to prevent the subsequent freezing of any moisture which it may contain, the air enters the reducing valve, of which we show a sectional view, where its pressure is lowered from 2,400 pounds to 320 pounds to the square inch. It then passes to the throttle valves at each end of the car, and thence to the injector, where a proper amount of moisture is sprayed into the air from the heater, the temperature of the spray being, of course, 400°. The air with the moisture which it has taken up now passes through a spiral coil in the heater (see detail view), where its temperature is raised to that of the heater, or 400°, at which temperature and corresponding pres

sure it enters the high pressure cylinders. From the high pressure cylinders it is carried direct to the low pressure cylinders and then exhausts to the atmosphere on the under side of these cylinders through a muffler. The exhaust, except at starting, is scarcely audible.

It will be seen that the system of the American Air Power Company differs very materially from that of the Hardie system, which we have already described at considerable length in this journal. (See SCIENTIFIC AMERICAN of January 30, 1897.) In the latter system the air is allowed to pass freely through the hot water of the heater, but this method has the serious defect of being liable to carry excessive quantities of water into the motors, and of reducing the pressure in the heater from that of air to the pressure necessary to maintain the water at a temperature of 400°, and these drawbacks are avoided by the type of heater used on these cars. The moisture taken up by the air has the double advantage of giving a better packing at the joints and of serving to maintain the pressure throughout the full stroke of the pistons by continually vaporizing during the advance of the piston after the point of cut-off. The speed of the car is controlled partly by the variation of the cut-off and partly by the manipulation of the throttle, the control in both cases being operated from the platform, where there are two handles, the upper one working the throttle, the lower one the cut-off. The cut-off has four notches corresponding to three variations in the speed and the full stop.

Under the present conditions of working, the cars have a capacity of fifteen miles with a charge of air occupying all space intermediate the seats, or the capacity could be increased up to as high as forty miles by placing on the cars as large a number of flasks as could possibly be crowded in, or it could be increased by raising the working pressure, a change which the company is now about to make. The motion of the cars is very agreeable; there is an absence of jar such as is noticeable on the cable and electric roads, and we understand that, as far as they have been tested, they are giving great satisfaction. We are indebted for our particulars to the courtesy of Mr. W. Hoadley Knight, the engineer of the American Air Power Company.



GENERAL PLAN OF 1,000 HORSE POWER COMPRESSORS AND CHARGING STATION.

ENGINEERING NEWS.

November 2, 1899.

COMPRESSED AIR STREET CARS on the Hardie system are used on the North Clark St. cable line, in Chicago, during the night hours when the cable plant is shut down, from 12.45 to 5.45 a. m., and 12.45 to 7.45 a. m. on Sundays. Since May 30 the cars have run 6,487 miles and have carried 71,155 cash passengers, or 77 passengers for each round trip of 7 miles. The compressor plant is in the cable power house at Clark and Elm Sts., and has been in actual operation for 443 hours, while the cars have been in actual operation for 598½ hours. Four-wheel cars are used, which are very similar to the cars which have been in service for about a year on 125th St., New York city. The system is being introduced in Chicago by the Compressed Air Motor Co.; President, Henry D. Cooke; Engineer, Robert Hardie.

COMPRESSED AIR.

BY

FRANK RICHARDS, MEM. A.S.M.E.

182 *A LIST OF THE VARIOUS APPLICATIONS.*

1st Edition
1899

Cars, Propelling, on Street Railways.—Compressed air is not yet extensively used for this purpose in the United States, but is permanently established and successful in Paris and elsewhere in Europe. Experimental cars in the United States show excellent results, and the general adoption of the system in the near future is more than probable. In cost of plant, in facility of introduction, in economy of operation, and in the entire absence of objectionable features the compressed-air system surpasses all others. The principal delay as to its extensive introduction is in determining the ultimately best of many details of construction and operation.

STREET RAILWAY JOURNAL.

MARCH 31 1900.]

Mahon was first called in the Third Avenue matter. When he left the Criminal Court Building he declined to talk of his testimony. As a member of Naughton & Company, who had the contract for changing the motive power of the Third Avenue, he was, of course, questioned about getting the contract which Isaac A. Hopper believed he had secured, and the employment of laborers who appeared to have sinecures. He was also questioned as to the profitable terms of the contract, 15 per cent on labor and 10 per cent on material, and the claims filed against the company.

Consolidation of Compressed Air Companies

It is understood that negotiations have practically been completed looking to the consolidation of nearly all the compressed air power companies in this country. These companies are controlled by various interests known as the Whitney, Hoadley, Croker and Leiter syndicates, and the companies which it is said are to compose the new concern are the American Air Power Company, of New York; the Storage Power Company, of New York; the Hydro-Pneumatic Storage Company, of Washington; the Hydro-Pneumatic Car Company, of Washington; the Standard Power Storage Company, of Philadelphia; the Tramway Power Storage Company, of Philadelphia; the International Power Storage Company, the International Air Power Company, The International Power Company, operating in Rhode Island, and the New York Auto-Truck Company.

It is expected that the parent company will either be the American Air Power Company or the International Power Company.

H. H. Vreeland, of the Metropolitan Street Railway Company, and who is president of the American Air Power Company, is reported to have said a few days ago when asked as to the matter that the negotiations had reached a stage which practically insured their successful termination.

It is stated also that the Metropolitan Company intends to increase the use of compressed air for operating its crosstown and horse car lines on both its own and the Third Avenue Railroad systems. A contract for 125 cars, which will be equipped with air motors has been made, and their installation on the various lines will be brought about as speedily as possible.

STREET RAILWAY JOURNAL.

APRIL 14, 1900.]

President Cooke of the Compressed Air Company Makes a Statement

President Henry D. Cooke of the Compressed Air Company, which was incorporated April 9 with a capital of $8,000,000, has issued an official statement, in part as follows:

"Announcement is made of the Compressed Air Company, with a capital of $8,000,000, incorporated under the laws of the State of New York, for the purpose of acquiring the ownership of the American Air Power Company, of New York, and the Compressed Air Motor Company, of Illinois.

"When all outstanding stock of the American Air Power Company and of the Compressed Air Motor Company are exchanged there will still remain in the treasury of the new company more than $1,000,000 of unissued stock, none of which will be offered for sale. Abundant cash for the treasury has been provided without selling any stock.

"The company begins business with orders from the Metropolitan Street Railway of New York for twenty-eight cars, now being constructed, and for 100 additional cars to follow, which will operate every crosstown line of the Metropolitan system. Negotiations are about being consummated for air cars on other roads, and twelve miles of road in the interior of the State of New York are at present under contract and will be operated with air cars within sixty days, the service being already partially established.

"The air cars which for a year past have been performing the night service on the North Clark Street line, Chicago, during the zero weather, blizzards and snowstorms of the past winter, have proved more reliable than any of the other forms of street car service in Chicago, and have made friends with the street railway managers and the public, and large business promised from the various street railways in Chicago."

The directors of the company are: William L. Elkins and Thomas Dolan, of Philadelphia; G. E. P. Howard, Henry D. Cooke, Francis R. Foraker, William C. Duxbury, Charles H. T. Collis, Howell C. Knight and William H. Kimball, of New York.

The following officers have been elected for the ensuing year: President, Henry D. Cooke; vice-president, C. H. T. Collis; secretary and treasurer, Henry A. Himely; chief engineer, Robert Hardy. The offices of the company will be located at No. 621 Broadway, New York.

Current Literature April 1900

APPLIED SCIENCE: INVENTION AND INDUSTRY

The Century's New Power... ...H. D. Cooke.....Leslie's Weekly

Compressed air and electricity are secondary forces, the handmaids and servants of steam, or other primary powers—their conservators and distributers. Each has special spheres of usefulness in which each excels, and neither should be placed in false mechanical positions by its too ardent advocates. As the work that each can do better than the other is understood, rivalry ceases. It has been well said that the "strongest manifestation of power is its widest distribution." In the field of power distribution where distance alone is considered, electricity excels; but wherever large volumes are required, compressed air is without a rival.

The elasticity of air is a natural law, hence it is unfailing in its operation. Released from pressure it returns to atmospheric density. It is not changed in compression, but can be kept indefinitely, and is regular in its operation. It is absolutely free from the vagaries of its brilliant but volatile ally, electricity. All nature is a vast air-using machine. What better can man do in mechanical devices than imitate nature? Steam-using engines operate with air. The application of air power is a proved mechanical fact. First chosen for special work in mines and other places, regardless of economy, now that its niceties are understood, its use is extending in all mechanical fields. Early used for air brakes, it made its way upon the railways and extended into general use for operating signals and switches, and then in the shops. It is now used in all lines of industry, in individual machine work, drills, pumps, etc.

It is passing strange that, after its successful use in brakes for stopping trains, it was not earlier used for propelling trains, a field into which it is now largely entering. In several cities of France there are street railroads operated with compressed air; in Berne, Switzerland, and elsewhere in Europe. Air motors of American design, to meet the high requirements of service in this country, are in successful operation in Chicago and New York City, and find favor with the street railroads and the public. Properly constructed, they are found to be noiseless and free from nuisance, and in economy of operation and maintenance excel all other forms of street railway traction. Compressed air is keeping pace with other powers for automobile propulsion. It is in use on a light wagon, the engine of which weighs thirty-six pounds. This wagon seats two people, and is propelled a mile with sixty feet of free air. In Europe Paris is the largest user of compressed air. There are many miles of mains, serving customers with air through pipes and meters, as gas is distributed, and operating machines, large and small, in all lines of industry. The loss in conveying air through these mains is stated to be only 3 per cent. This system started at St. Fargeau Station with a capacity of 2,500 horse-power. Other stations have been established with a total capacity of 24,000 horse-power.

Elevators and other engines in the Paris Bourse are operated with air; also electric dynamos, distributing currents to incandescent lights. In this instance the air is not heated, but used cold, and the exhaust furnishes refrigeration to cold-storage rooms, where meats, vegetables and other products are stored. Butchers, caterers and hotels are in this manner supplied with refrigeration. The pneumatic telegraph-postal system has been in use for thirty years in Paris for delivery of telegrams. Similar services exist in London, Berlin and other European cities. It is gratifying to note the establishment of a similar system in this country. In New York there are now twelve miles of eight-inch tubes, connecting the main post offices of New York and Brooklyn, and extending to the New York Central Railroad depot. Letters placed in sealed carriers are transmitted at a velocity of over thirty miles per hour, and the mail from Brooklyn post office, formerly closing two and one-half hours before, now closes twenty-five minutes before the departure of New York Central trains.

As the tendency is toward higher pressures, liquid air suggests interesting and prolific possibilities. To an American belongs the honor of first producing it in commercial quantities. Its use in mechanics is limited, owing to present cost of production, which will be cheapened, no doubt. It is made by compression and self-refrigeration, the latter accomplished by liberating and expanding compressed air about coils that contain air under pressure. The temperature of liquid air is 312 degrees below zero, Fahr. Its chief advantage is its compactness in storage, approximately 800 feet of free air being contained in one foot of liquid air.

STREET RAILWAY JOURNAL.

AUGUST 4, 1900.]

Compressed Air Cars in New York

Considerable interest has been aroused by the proposal of the Metropolitan Street Railway Company, of New York, to change the type of compressed air motors in use on its Twenty-Eighth and Twenty-Ninth Streets Railway. Reference has already been made to the fact that the Hardie motors are to be used on this line in place of the motors which have been employed, and which were described at length in the STREET RAILWAY JOURNAL for June, 1899. The reasons for this change can best be explained by a brief history of compressed air traction in this country dur-

ing the last three years. About three years ago two manufacturing companies were making vigorous efforts in New York to solve the problem of the application of compressed air to street car service. One of these was the General Compressed Air Company, which was operating three motor cars on the 125th Street line of the Third Avenue Railroad Company; the other was the Compressed Air Power Company, which was owned largely by some of the principal stockholders of the Metropolitan Street Railway Company. These gentlemen were induced to become interested in compressed air traction, largely by the hope that independent compressed air cars could be used on the cross-town lines of the Metropolitan Street Railway Company, on which the installation of the underground conduit was practically out of the question on account of expense, and on which the installation of the overhead trolley was prohibited by the municipal authorities.

The motors used by the two systems mentioned, and which were popularly known respectively as the Hardie and Hoadley systems, were alike in that a high pressure, *i. e.*, 2000 to 2500 lbs. per square inch was carried in the air reservoir, but differed in practically every other respect. In the Hardie system, two long stroke (14 ins.) single expansion engines were carried on the car truck and drove directly the wheels of one axle of the car, the other axle being connected to the driven axle by side rods. The Hoadley motors on the other hand were patterned more after an electric motor, so far as the application of the power was concerned. Each motor, of which there were two on each car, was of the compound type with short stroke (6 ins.), and drove a shaft carrying a pinion which in turn was geared to the car axle. The two axles were thus driven independently, the motors ran in oil, and the whole equipment did not differ very much in external appearance from an electric equipment. There were a great many other variations in practise between the Hardie and Hoadley systems, as in the method of reheating, etc., but those already mentioned are sufficient to characterize the two systems as radically different.

The satisfactory results secured by the Hardie motors on the Third Avenue line, as mentioned above, convinced the managers of the Metropolitan Street Railway Company that the patents of the General Compressed Air Company were essential in securing the best results in compressed air motor work. As a consequence, negotiations were entered into by which a new company, the American Air Power Company, was formed to consolidate the interests of the other two. The Metropolitan syndicate controlled the new company, and though certain modifications were made, the general characteristics of the systems used on the Metropolitan line remained the same, that is, the compound short stroke motor driving the two axles independently. Soon after the consolidation, the services of Robert Hardie were secured by the Compressed Air Motor Company, which was a licensee for Wisconsin and Illinois of the General Compressed Air Company, and whose stockholders still believed in the "locomotive" principle, as applied to compressed air traction. The scene of the competitive trial between the two systems was now transferred, the American air power motors being used in New York, while the Hardie motors were employed in Chicago. The Chicago motors were used on the North Clark Street road, to operate between 12 o'clock at night, when the cable of that line shut down, and 6 o'clock next morning, when the cable was again put in operation. The motors gave good satisfaction and frequently hauled a trail car, and sometimes two trail cars, with a total of 300 passengers on a train. The results secured were so much more satisfactory than those in New York that the Metropolitan syndicate decided that if success was to be secured in the latter city, it would have to be, by following the Hardie system as employed in Chicago. Negotiations were then entered into between the American Air Power Company and the Compressed Air Motor Company for a second consolidation of interests, and resulted in the organization of the Compressed Air Company, with Mr. Hardie as chief engineer for the consolidated company. Henry D. Cooke, the president of the Compressed Air Motor Company, was also elected president of the new company. This has resulted in the retirement of the old equipment on the Twenty-Eighth and Twenty-Ninth Streets lines, and the placing of an order by the Metropolitan Street Railway Company for the equipment of the line with the Hardie motors. The new motors for the Twenty-Eighth and Twenty-Ninth Streets lines are now being built, and will be in operation at an early date. It is the purpose of this article to describe the system as it will be employed on this road, as fairly representing the best American compressed air practise at the present date.

The compressing station is located at the foot of West Twenty-Fourth Street, New York, western terminus of the line, and was fully described in the STREET RAILWAY JOURNAL for June, 1899. It contains a 1200-hp engine, operating directly four-stage Ingersoll-Sergeant air compressor, with a capacity of 56,735 cu. ft. of free air per revolution, and compressing to 2500 lbs. per sq. in. This air is stored in a series of reservoirs of seamless tube flasks in the car house, from which the reservoirs on the cars are charged.

There are sixteen reservoirs on the cars, having an aggregate capacity of 55 cu. ft., and weighing 4340 lbs. Fourteen of these reservoirs are carried on the truck, and one under each seat. From these reservoirs the air passes into one common header, and from this header is a pipe passing to each end of the motor car. The flow of air through this pipe is regulated by a stop valve under the control of the motorman When the motorman opens the valve at either end of the car, the air, which is still

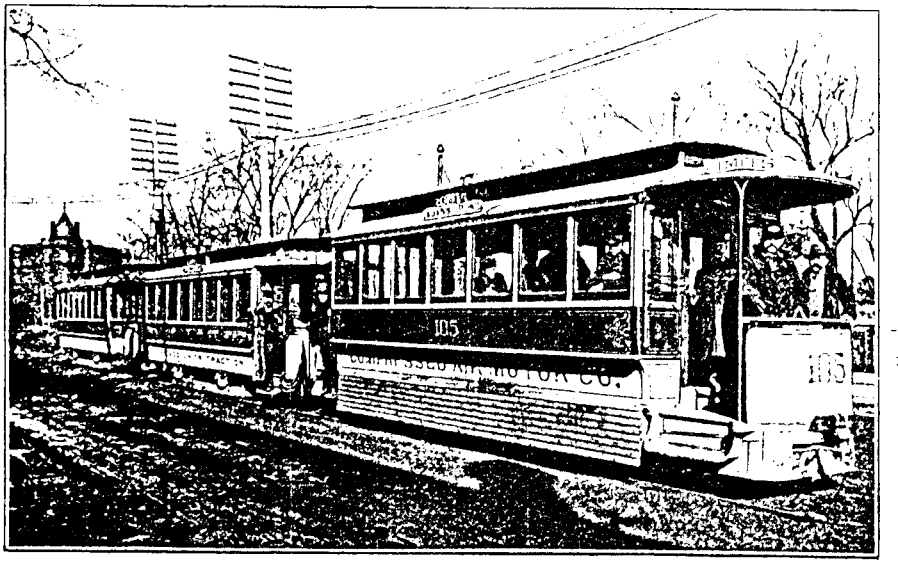


FIG. 1.—COMPRESSED AIR MOTOR CAR AND TWO TRAILERS, NORTH CLARK STREET, CHICAGO

under 2500 lbs. pressure, passes from the valve to the reducing valve.

The reducing valve is illustrated herewith, and automatically keeps the working pressure uniformly at about 150 lbs. per sq. in., whether the storage pressure is at its maximum or its minimum or at any intermediate point. As will be seen, the reduction valve is balanced by a hydraulic packed piston (shown below the reduction valve) in such a way that a variation in the storage pressure, as would be experienced during a trip, does not affect the operation of the valve. Ordinarily, double valves are used for this purpose, but these rarely give a constant reduced pressure, with a variable high pressure; they also give trouble by leakage. As will be seen, there is a spring which tends to open the reduction valve, and whose pressure is balanced by a flexible disc, upon which the reducing pressure acts, tending to close the reducing valve. When this reduced pressure reaches a point sufficiently high to compress the spring, it seats the valve automatically.

The cap which closes the opening through which the valve is passed into its place is also a cylinder, in which is another hydraulic packed piston. The object of this piston is to enable the motorman to increase the working pressure for starting quickly from a state of rest. Its operation is as follows: A pipe connects the space *A* with the motorman's brake valve, and when the brake handle is moved to a certain position it bleeds the air from pocket *A*. The working pressure then acts on the under side of this piston to assist the spring in opening the valve. It now requires a higher pressure acting on this disc to close the valve against the combined resistance of the spring and this piston, which higher pressure enables the motor to start quickly. As soon as the motor has acquired the necessary speed, the motorman moves the brake handle to the normal running position, which restores the working pressure in the space *A*, so that the piston is now in equilibrium

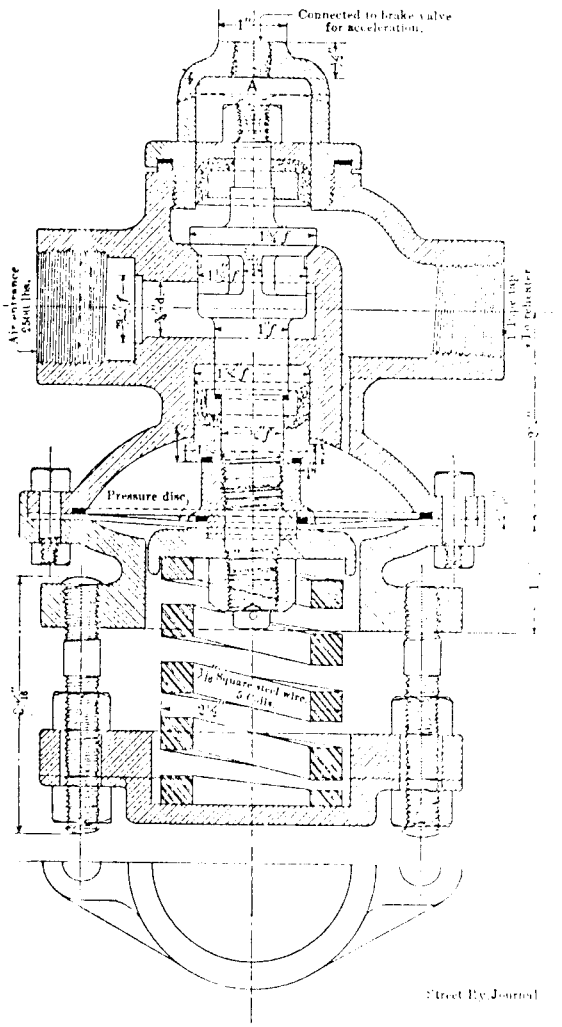


FIG. 2.—SECTION OF REDUCING VALVE

and the normal working pressure is now sufficient to close the valve against the spring and keep the motor in operation.

It will be noticed that the valve itself is connected by ribs or wings to a collar on the valve stem. This is done as a matter of safety. Should the valve stem break at any point under this collar, the entering high pressure would immediately open the valve, but the collar entering the seat prevents a dangerous rush of air into the working pressure reservoirs and pipes. It will also be noticed that the follower of the equalizing piston has a shoulder which will permit of 1-16 in. movement of the valve in ordinary working, so that the safety collar can never enter the seat unless the valve stem breaks.

After passing through the reducing valve, the air is at working pressure of 150 lbs., and is then led to the reheater, which is placed in the middle of the truck. This reheater contains about 500 lbs. of hot water, the temperature of which at the start is about 320 deg. F., but during a trip this temperature falls sometimes as low as 170 deg. The air is passed into the bottom of this heater and escapes

into the water through a perforated pipe lying along the bottom of the heater. When the reservoirs need to be recharged with air, and the car is run to the charging station for this purpose, steam is passed through this same perforated pipe to reheat the water.

During its passage through the water, the air is heated to the temperature of the water, and is then drawn off at the top through the perforated pipe *T*. The baffle plates shown are to prevent a swash of water caused by the car oscillation.

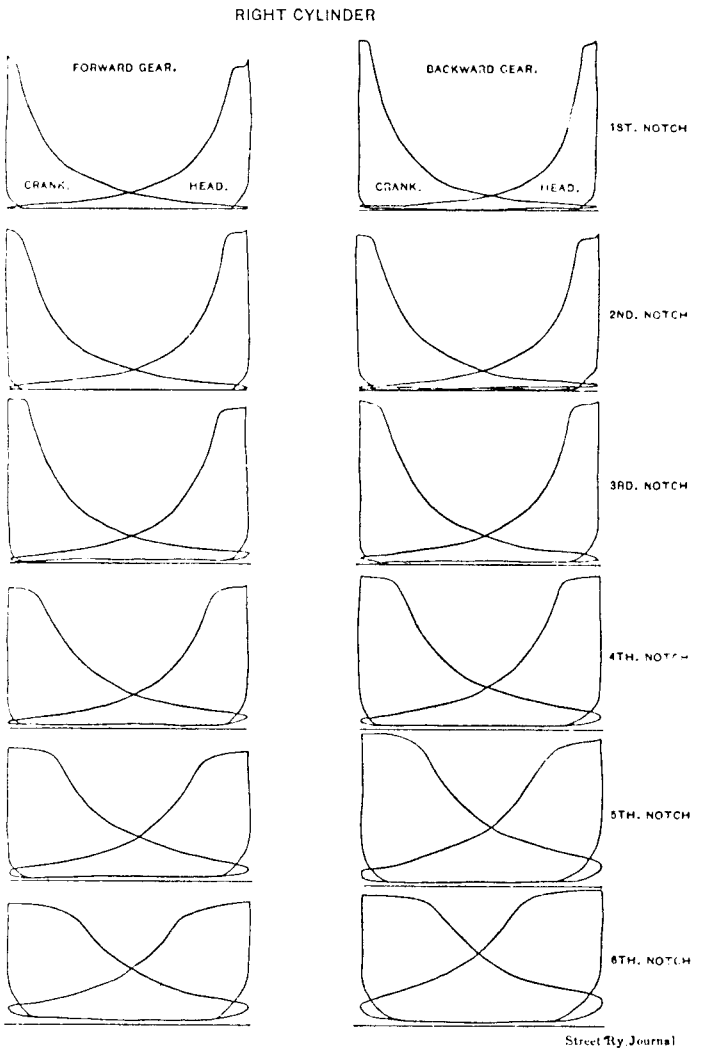


FIG. 3.—TYPICAL INDICATOR DIAGRAMS AT DIFFERENT NOTCHES

The efficiency of reheating is illustrated by the following test: A motor was run two trips, as far as possible each trip, on a full charge of air, first without heat and afterward with heat, covering 8 miles and 15 miles respectively; showing that the additional 7 miles were obtained from the heat, and careful measurements showed that the amount of heat used was 98,000 heat units. In ordinary practise, from 10 to 12 lbs. of coal will supply this amount of heat to generate steam in steam boilers. As this amount of steam injected into the water in the heater will restore the 98,000 heat units, it follows that the additional 7 miles were obtained on an equivalent of from 10 to 12 lbs. of coal.

Returning now to the cycle of operations, the air, which is now at about 150 lbs. pressure, and at a temperature of about 320 deg. F., passes from the perforated exit pipe *T* to the throttle valve of the motor, and thence to the valve chest of the engine in exactly the same way as steam in a steam engine.

The valve chest of the engine cylinders contains two valves, one the distribution or main valve, and the other the cut-off valve. These valves are operated in such a manner that any degree of cut-off can be obtained, as illustrated by the indicator diagrams. Compressed air has this advantage over steam, that it does not condense during expansion in the engine cylinder. Therefore, expansion may be carried with economy clear down to atmospheric pressure. To do this in a steam engine would cause what is known as cylinder condensation. Steam engines are compounded principally to reduce this cylinder condensation to a minimum, but this is not necessary with compressed air.

It was necessary to contrive a valve mechanism which would not be too complicated to operate, and yet obtain the best results. The valve mechanism which is attached to these motors is illustrated in Fig. 4. The usual Stephenson link motion is used to operate the main valve, but on the outside of the link there is an arm *a*, looking down as well as up. At the lower end of the lower arm *a* is attached the lower end of a floating lever, *f*. The upper end of lever *f* receives a reduced motion, which is the opposite of the piston, through the lever *g* and link *l*, lever *g* being pivoted by a bracket attached to the frame at the point *p*. It will be observed that the lower end of floating lever *f* receives a motion directly the opposite of the main valve, and that its upper end has a motion directly the opposite of the piston rod. This lever *g* is attached to the cut-off rod at the point *m*, and gives to the cut-off valve a motion which is the resultant of the other two. The consequence is that when the main valve is traveling in full gear, the cut-off valve is also traveling at its longest stroke, and gives the earliest cut-off. When, however, the link motion is "cut back" so as to reduce the motion of the main valve, it gives a later cut-off. The indicator cards, shown in Fig. 3, indicate the effect of this. The first notch indicates the full travel of both valves, and each succeeding notch a reduced travel of both valves, showing a later cut-off. It will be observed that the latter grades show some terminal pressure which produces an audible exhaust, but these grades of cut-off are used only for starting the motor, and the lever is immediately moved to a position corresponding with either of the first three notches, according to the power required, which depends upon the loads and grades. It will be observed while cutting off at the earlier notches there is a freer exhaust, which will more readily free the cylinder when going fast. In the ordinary locomotive the cutting off is effected by the link motion only, with the result that the exhaust openings are diminished.

It will also be observed that the various grades of cut-off within the control of the motorman are effected by the same lever which reverses the motion, thus simplifying the operation of the motor very materially, and bringing it within the comprehension of the average street railway employee.

The weight of the entire equipment is said to be practically the same as an electric equipment, and all parts are

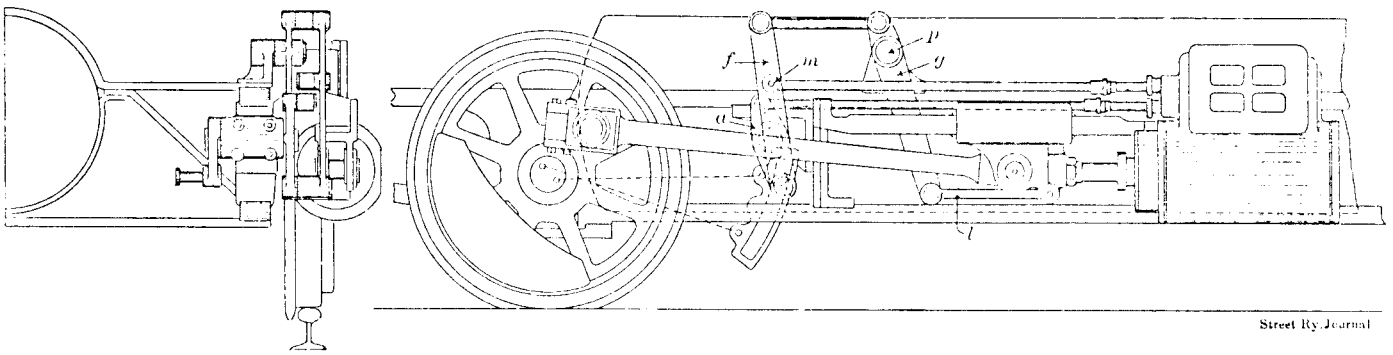


FIG. 4.—DIAGRAM OF ENGINE CYLINDER, SHOWING VALVE GEAR

RESULTS OF DISTRIBUTION OBTAINED BY HARDIE VALVE GEAR FOR THREE POSITIONS OF LINK, WITH 3-16 IN. INSIDE AND OUTSIDE LAP OF MAIN VALVE AND 11-16 IN. NEGATIVE LAP OF CUT-OFF VALVE

ADMISSION PORTS 2½ INS. X ⅝ INS. CYL. 6½ INS. X 12 INS.

FIRST POSITION
Main Valve (Full) Travel 2 in.; Cut-off Valve Travel 2 in.

Crank Angle	Cut-off Valve Opening		Main Valve Opening		Piston Travel	
	Front	Back	Front	Back	Front	Back
Deg.	In.	In.	In.	In.		
0	15-16	⅞	7-32	7-32	.0	.0
10	21-32	19-32	3⅜	3⅜	.11	.08
20	11-32	5-16	½	½	.42	.31
30	0	0	5⅜	21-32	.94	.67
40	— ¼	— ¼	11-16	¾	1.61	1.20
50	— ½	— 15-32	¾	27-32	2.46	1.83
60	— 11-16	— 23-32	⅞	⅞	3.39	2.62
70	— ⅞	— 29-32	¾	15-16	4.44	3.48
80	—1 1-32	—1 1-16	¾	15-16	5.47	4.45
90	—1 3-32	— 1⅛	11-16	⅞	6.53	5.48
100	— 1⅛	— 1⅛	21-32	25-32	7.55	6.54
110	—1 1-32	—1 3-32	½	21-32	8.54	7.56
120	— 15-16	— 31-32	13-32	½	9.39	8.62
130	— 25-32	— 27-32	9-32	5-16	10.17	9.54
140	— ⅝	— 11-16	⅛	5-32	10.81	10.39
150	— 13-32	— 15-32	— 1-32	— 1-32	11.33	11.06
160	— ⅛	— 7-32	— 7-32	— 7-32	11.70	11.58
170	1-16	3-32	—13-32	— 3⅛	11.93	11.89
180	15-32	13-32	— 9-16	—19-32	12.00	12.00

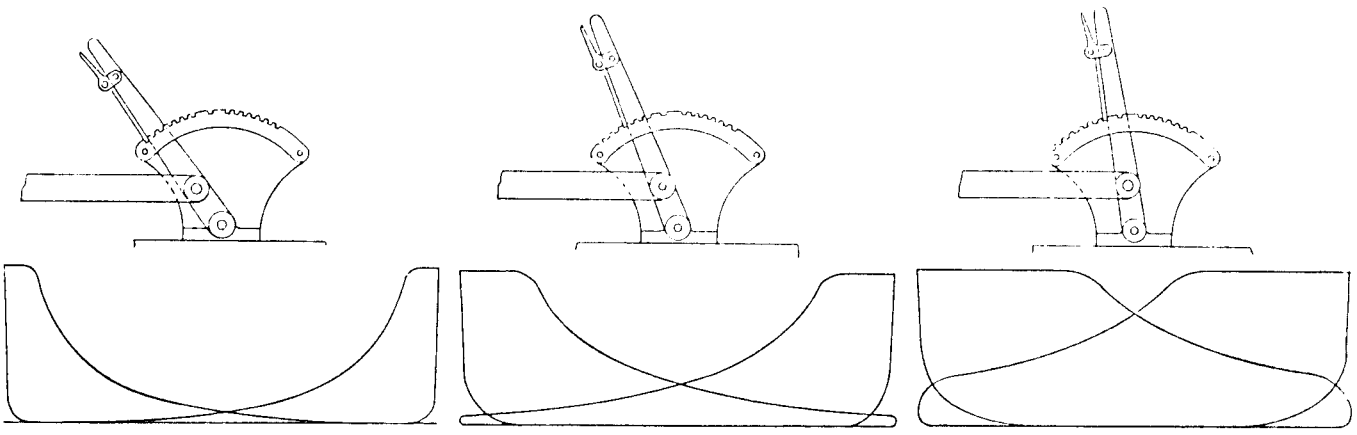
SECOND POSITION
Main Valve Travel 1½ in.; Cut-off Valve Travel 1 11-16 in.

Crank Angle	Cut-off Valve Opening		Main Valve Opening		Piston Travel	
	Front	Back	Front	Back	Front	Back
Deg.	In.	In.	In.	In.		
0	1	1 1-16	5-32	5-32	.0	.0
10	13-16	⅞	¼	9-32	.11	.08
20	9-16	19-32	11-32	3⅜	.42	.31
30	5-16	3⅜	7-16	7-16	.94	.67
40	1⅛	5-32	15-32	15-32	1.61	1.20
*50	— 3-32	— 1-16	9-16	19-32	2.46	1.83
60	— ¼	— ¼	9-16	19-32	3.39	2.62
70	— 7-16	—13-32	9-16	⅝	4.44	3.48
80	— 9-16	— 9-16	½	9-16	5.47	4.45
90	—21-32	— ⅝	7-16	½	6.53	5.48
100	—11-16	—21-32	⅜	7-16	7.55	6.54
110	—21-32	— ⅝	5-16	3⅜	8.54	7.56
120	—19-32	— 9-16	¼	9-32	9.39	8.62
130	— ½	— 7-16	3-32	⅛	10.17	9.54
140	— ¾	— 5-16	— 1-32	— 1-32	10.81	10.39
150	— 9-32	— 5-32	— 9-64	— 5-32	11.33	11.06
160	— ⅛	— 1-32	— 1-64	— 9-32	11.70	11.58
170	1-16	5-32	— ⅛	—13-32	11.93	11.89
180	5-16	3⅜	— ½	—17-32	12.00	12.00

THIRD POSITION
Main Valve Travel 1 in.; Cut-off Valve Travel 1½ in.

Crank Angle	Cut-off Valve Opening		Main Valve Opening		Piston Travel	
	Front	Back	Front	Back	Front	Back
Deg.	In.	In.	In.	In.		
0	1 1-16	1⅜	⅛	7-64	0	.0
10	15-16	1	5-32	5-32	.11	.08
20	13-16	29-32	7-32	7-32	.42	.31
30	21-32	¾	¼	9-32	.84	.67
40	17-32	19-32	¼	5-16	1.61	1.20
50	½	7-16	¼	5-16	2.46	1.83
60	½	5 16	¼	5-16	3.39	2.62
70	⅛	5-32	7-32	5-16	4.44	3.48
80	0	0	3-16	5-16	5.47	4.45
90	—1-16	—1-16	5-32	9-32	6.53	5.18
100	— ⅛	—3-32	3-32	3-16	7.55	6.54
110	—5-32	—3 32	1-64	⅛	8.54	7.56
120	—5-32	—3-32	— 1-16	1-32	9.39	8.62
130	— ⅛	—1-16	— ⅛	— 3-32	10.17	9.54
140	—3-32	0	— 3-16	— 5-32	10.81	10.39
150	0	3-32	— 9-32	— 9-32	11.33	11.06
160	1-16	3-16	—11-32	— 3⅜	11.70	11.58
170	⅛	9-32	—13-32	— 7-16	11.93	11.89
180	7-32	5-16	—15-32	—15-32	12.00	12.00

* Cut-off at 47 deg. Average piston travel, 1.91 in.



Main cut-off and compression crank angle, 148 deg.
Lead angle of crank—front, 12 deg.; back, 12 deg.
Point of cut-off, not including clearance, $\frac{1}{14.81}$ of stroke
Point of cut-off, including clearance, $\frac{1}{9.54}$ of stroke
Greatest port opening, 7-16 in.
Relative travel of main and cut-off valves, 3⅛ in.

Main cut-off and compression crank angle, 138 deg.
Lead angle of crank—front, 13 deg.; back, 13 deg.
Point of cut-off, not including clearance, $\frac{1}{6.29}$ of stroke
Point of cut-off, including clearance, $\frac{1}{5.19}$ of stroke
Greatest port opening, ⅜ in.
Relative travel of main and cut-off valves, 2 11-16 in.

Main cut-off and compression crank angle, 117 deg.
Lead angle of crank—front, 18 deg.; back, 18 deg.
Point of cut-off, not including clearance, $\frac{1}{2.42}$ of stroke
Point of cut-off, including clearance, $\frac{1}{2.29}$ of stroke
Greatest port opening, 9 32 in.
Relative travel of main and cut-off valves, 1⅝ in.

The variation of cut-off is effected by changing position of reverse lever (see above sketches), and grades of cut-off are obtainable between those given in the tables, the earliest grades being when lever is full over, so as to give valve full throw. In this position there is also the greatest amount of lead. Cut-off, including clearance, means $\frac{\text{piston travel at cut-off + clearance}}{\text{stroke of piston + clearance}}$; clearance in cylinder, 4 per cent.

Inside and outside lap being equal, main valve cut-off and compression take place at the same point.

The greatest port openings noted above are taken at the point where cut-off and main valve openings are equal, the cut-off closing while the main valve is opening. In the earlier grades this takes place near beginning of stroke when piston is moving slowly, and in the later grades when motor is moving slowly. There is always ample exhaust opening.

Readings were taken at equal crank angles for convenience, but valves would be set to cut-off at equal piston movements from each end of cyl.

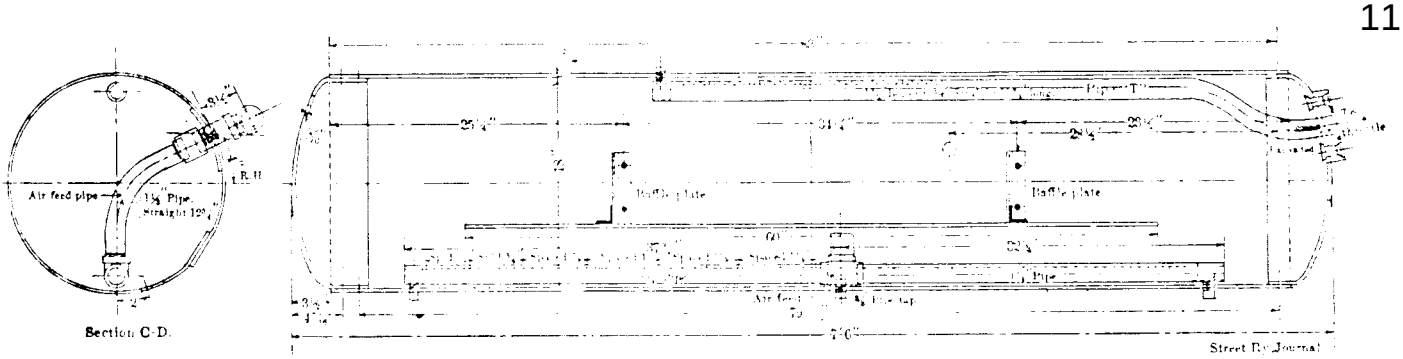


FIG. 5.—SECTIONS OF REHEATER

flexibly supported on the axle box by means of four semi-elliptical springs, after the most modern locomotive practise. This support is entirely separate from that of the car bodies, which are carried on a different set of springs resting on the frame of the truck. In this use of flexible suspension, the system differs radically from the former air motors used on the Twenty-Eighth and Twenty-Ninth Streets line, where the case carrying the motors rested directly on the axles.

There remains now only one portion of the equipment to be described, *i. e.*, the air brakes. The air brake cylinder is illustrated in section in Fig. 6. In applying the brakes air is admitted to the annular space *R*, around the hollow piston rod, and to release the same air is made to pass to the other side of the piston from *T* around through *V*, thus equalizing on both sides of the piston. Having a larger area to act upon on the other end, the brake is released at once, the air escaping silently through the small opening *S*, and out to the atmosphere through the openings at *W*, at the end of the plunger.

The Twenty-Eighth and Twenty-Ninth Street railway is now being operated by horses pending the change from the Hoadley-Knight to the Hardie motors. There is every reason to expect that these new motors will be successful, because Mr. Hardie has had more experience in this line than any other engineer in the United States, and has made the subject a special study for years. He has, moreover,

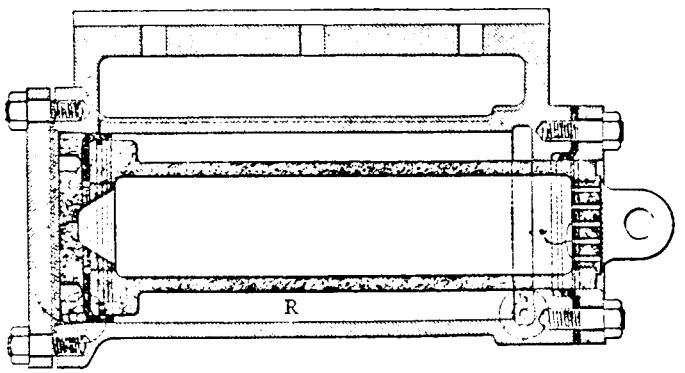


FIG. 6.—AIR BRAKE CYLINDER

held many responsible positions, and stands high in the profession. His standing among engineers is well expressed in the following extract from *Compressed Air*: "His mechanical ideas are marked by much individuality, the elements of simplicity being prominent. It is doubtful if any one has had as much experience as Mr. Hardie in pneumatic traction, and he is the acknowledged authority on the subject."

Scientific American.

AUGUST 25, 1900.

COMPRESSED AIR TRACTION IN NEW YORK CITY.

An important change is being effected in the compressed air system of traction on certain lines in this city, by the substitution of what is known as the Hardie motors for those now in operation, which were built under what are known as the Hoadley patents. What might be called the modern development of compressed air traction in New York dates from about the year 1897, when the promoters of the two types of motor mentioned above were engaged in active experimental work, the Hardie system being tried on the Third Avenue Railroad, and the other on the lines of the Metropolitan Street Railway Company. Both motors operate under extremely high pressures of from 2,000 to 2,500 pounds to the square inch; but here the difference ends. In the Hardie system two long-stroke, single expansion engines are employed, which are directly connected to one axle of the car, the other axle being driven by side rods. The air, after being reduced to the working pressure by a reducing valve, passes through a tank of hot water, and is then led in a super-heated condition to the cylinders. The Hoadley motor differs from this mainly in the fact that a complete two-cylinder, compound engine is carried on each truck and drives a shaft which is geared down to the car axle. Instead of passing the air bodily through the tank of hot water, a small jet of water is sprayed into the air pipe between the reducing valve and the cylinders.

The Hoadley system was adopted by the Metropolitan Street Railway Company, while the Hardie system has been for some time in successful operation on the North Clark Street Railroad, Chicago. The recent amalgamation of the two companies has resulted in the adoption of a motor designed chiefly upon the lines of the Hardie system, which will shortly replace the motors now in use upon the crosstown lines of the Metropolitan Street Railway system. The present compressing station, which is located at the foot of West Twenty-fourth Street, will be utilized, and it is expected that before very long the new motors will be in operation. Mr. Hardie, who is the chief engineer of the Consolidated Compressed Air Company, which now has control of the patents covering both systems, is one of the oldest and most indefatigable workers in the field of compressed air traction, and the success of the new

venture will be watched with considerable interest by the Metropolitan Street Railway Company, to whom the development of a really satisfactory independent motor for their crosstown lines seems to be almost an imperative necessity.

American Institution of Mining Engineers
Transactions 130 (1900): 566-73.

Notes on the Compressed-Air Haulage-Plant at No. 6 Colliery of the Susquehanna Coal Company, Glen Lyon, Pennsylvania.

BY J. H. BOWDEN, WILKES-BARRE, PA.

(Canadian Meeting, August, 1900.)

THE shaft-plant here described was put in operation in September, 1895, and the No. 6 slope-motor was started in May, 1896.

The plant comprises:

One Norwalk three-stage compressor 12½, 9½ and 5 in. diameters of air- and 20 in. diameter of steam-cylinder, all 24 in. stroke; capacity at 100 revolutions, 296 cu. ft. of free air per minute, compressed to 600 lbs. per sq. in. A main pipe, 5 in. diameter, 4380 ft. long, with five charging-stations in No. 6 Shaft, and a branch of 3 in. pipe, 3100 ft. long, with three charging stations, in No. 6 Slope. These pipes on each line charge a Porter compressed-air motor, with 7 by 14 in. cylinders, and four 24 in. drivers, weighing about eight tons, with a tank-capacity of 130 cu. ft. of air at 550 lbs. pressure in the main tank, reduced to 160 lbs. in the 8-in. auxiliary tank of 4.2 cu. ft. capacity, supplying the cylinders. The No. 6 shaft run averages 4000 ft. each way on grades of ½ to 2¾ per cent., and averaging close to one per cent. in favor of the loaded cars. The No. 6 slope run averages 2100 ft. with nearly the same grades. The mine-cars weigh 2800 lbs. empty, and about 9800 lbs. loaded, and are hauled in trips of 12 to 20, averaging about 15 cars. The shaft-motor now hauls about 355, and the slope-motor 320 cars per day of 10 hours, replacing in the shaft 17 mules, and in the slope 15 mules, or, in all, 32 mules, against 27 replaced in 1896.

The average daily car- and ton-mileage of each motor was as follows:

No. 6 Shaft-motor,

Cars Hauled.

	1896.	1897.	1898.
	355	347.4	356

Tons Hauled One Mile.

	1896.	1897.	1898.
Empty, in,	336	330	338
Loaded, out,	1180	1155	1183
Total,	1516	1485	1521
Net load,	844	825	845

No 6 Slope-motor,

Cars Hauled.

	1896.	1897.	1898.
	288	288.7	319.2

Tons Hauled One Mile.

	1896.	1897.	1898.
Empty, in,	143	144	160
Loaded, out,	501	504	560
Total,	644	648	720
Net load,	358	360	400

Total for both motors, gross (including empty cars returned),

	1896.	1897.	1898.
	2160	2133	2241
Net load,	1202	1185	1245

The use of steam and air in operating the compressor and motor was found by test to be:

Steam.

Indicated horse-power at 131 revolutions of compressor,	150 H. P.	
Steam-consumption per H. P. per hour, from cards,	34 lbs.	
" per hour,	5,100 "	
" " including condensation in line,	5,200 "	
Boiler horse-power required,	174 B. H. P.	
Evaporation per lb. of coal (cylinder-boilers),	5 lbs.	
Coal required per hour,	1,040 "	
" per day, 10 hours,	10,400 "	4.65 tons.
Cost of fuel and firing per day (10 hours) 4.65 tons, at 50c.	$2.32	

Compressor Capacity.—The free air compressed per revolution of compressor is 2.96 cu. ft. according to the calculation of the Norwalk Iron Works Co., no allowance being made for leakage.

The compressor works 12 hours per day; the motors 10 hours.

	Cu. ft.
Free air per minute at rated speed of 100 revolutions,	296
" " " actual " 131 "	387.8
" per day 12 hours at rated speed of 100 revs.,	213,120
" " 12 " actual " 131 "	279,216

Capacity of Air-Mains Used as Reservoirs.—The capacity of the 5-in. line, 4380 ft. long, is 608 cu. ft.; and that of the 3-in. line, 3100 ft. long, is 159 cu. ft., making the total for both lines 767 cu. ft.

At 600 lbs. pressure these lines hold 32,505 cu. ft. of free air. The capacity of the main and auxiliary tanks is 134.6 cu. ft. At 508 lbs. pressure (at which they will equalize with the main, starting to charge at 600 lbs.), this is equivalent to 4845 cu. ft. of free air.

Leakage of Air-Mains.—In standing 12 hours the pressure falls from 550 to 350 lbs., and of free air, 11,688 cu. ft., or 974 cu. ft. per hour, are lost. The proportion of this leakage to the total air compressed is 4.18 per cent.

Air Used by Motors.—According to a test made March 29, 1900, the amount of air used for the given amount of work was as follows:

	Shaft-Motor.		Slope Motor.
	No. 2 Plane.	No. 3 Plane.	
Number of trips empty	3	10	16
" " loaded	3	10	15
Average No. of cars per trip, empty,	15.33	12.7	11.4
" " " loaded,	13	13	11.3
Average cu. ft. of free air per trip, empty	1724	5686	1230
Average cu. ft. of free air per trip, loaded	1631	1898	599
Average cu. ft. of free air per round trip	3355	7584	1829

Summary of Day's Work in 1898.—At shaft No. 6, 356 cars were hauled per day; namely, from No. 2 plane, 6 trips of 15 cars each, using 20,130 cu. ft. of free air, and from No. 3 plane, 20 trips, averaging 13.3 cars each, using 151,680 cu. ft. of free air. The work at Slope No. 6 was 320 cars per day in 28 trips, averaging 11.4 cars each, and using 51,212 cu. ft. of free air, making a total for 676 cars of 223,022 cu. ft. of free air. The amount of free air apparently compressed for this work was 279,216 cu. ft., of which 83.4 per cent. is accounted for, leaving 16.6 per cent. for leakage and slip in the compressor, leakage in air-lines, and changes in temperature.

Air Used per Ton-Mile.—The average volume of free air used per ton-mile is as follows:

	Cu. ft.
No. 6 shaft-motor, on gross tonnage,	113
" " " net "	203
No. 6 slope-motor, " gross "	71
" " " net "	128
Both motors, " gross "	100
" " net "	180

The greater quantity of air used by the shaft- as compared with the slope-motor is due to the heavier curves and the switching required, especially at No. 2 plane, where a portion of the trip is frequently left.

Cost of Plant.—The cost of plant, not including steam-boilers, was as follows:

Compressor,	$2,880.00
Extras for compressor-repairs,	75.75
Shaft-motor,	2,743.63
Slope-motor,	2,918.20
Extras for motor-repairs,	207.93
Air-connections, 5-in. line (6000 ft.),	2,914.32
" " 3-in " (4000 ft.),	1,240.46
Steam-connections to compressor,	278.27
Material for compressor-foundations and house, and air-washing box,	295.27
Labor on compressor-house and foundations, and 5-in. line, and installing shaft-motor,	1,183.01
Labor on 3-in. line and installing slope-motor,	46.95
Foster equalizing-valves,	372.21
Total cost of plant,	$15,156.00

Cost of Operation.—The operating expenses are shown in the following table:

	1897 (179 days worked).		1898 (160 days worked).	
	Per day.	Per year.	Per day.	Per year.
2 Motor-engineers, at $2.10	$4.20	$751.80	$4.20	$672.00
2 Brakemen, at $1.60	3.20	572.80	3.20	512.00
½ Engineer for compressor, at $2.32	1.16	207.64	1.16	185.60
Oil for compressor	.67	119.49	.47	75.94
Oil for motors	.25	45.08	.25	40.94
Repairs for compressors (material)	.10	18.76	.48	76.08
" " (labor)	.06	10.38	.09	15.22
Repairs for motors (material)	.16	28.78	.51	81.08
" " (labor)	.18	32.77	.23	36.87
Steam for compressor (150 H. P.), fuel and firing	2.32	415.28	2.32	371.20
Total operating-expenses	$12.30	$2202.78	$12.91	$2066.93

Fixed Charges.—The fixed charges are as follows:

	1897 (179 days worked).		1898 (160 days worked).	
	Per day.	Per year.	Per day.	Per year.
Interest, repairs and depreciation of 174-H. P. boilers	$1.46	$261.00	$1.63	$261.00
Interest and depreciation of plant, 10 per cent. on $15,156	8.47	1515.60	9.47	1515.60
Total fixed charges	$9.93	$1776.60	$11.10	$1776.60

Total Cost Including Fixed Charges.—The total actual cost in the two periods mentioned was, therefore, for the two motors (one-half to each), in 1897, per day, $22.23, and for the whole period, $3979.38; and in 1898, per day, $24.01, and for the whole period, $3843.83. Taking the figures of 1897 as a basis, and assuming 300 days of work in a year (with consequent saving in certain items of fixed charges, superintendence, etc.), it is estimated that the total cost would be $18.22 per day, or $5466.00 per year. A similar calculation, based upon the figures of 1898, gives $18.83 per day, or $5649.00 per year.

Cost Per Ton-Mile.—For the same two periods, the cost per ton-mile was as follows:

	1897 (179 days).			1898 (160 days).		
	Daily Ton-Milage.	Daily Cost.	Cost per Ton-Mile.	Daily Ton-Milage.	Daily Cost.	Per Ton-Mile.
			Cents.			Cents.
No. 6 shaft motor, gross	1485	$11.12	0.75	1521	$12.00	0.79
" " net	825	"	1.35	845	"	1.42
No. 6 slope-motor, gross	648	"	1.72	720	"	1.67
" " net	360	"	3.09	400	"	3.00
Both motors, gross	2133	22.23	1.05	2241	24.01	1.07
" net	1185	"	1.89	1245	"	1.93

Cost of Mules Displaced by this Plant.—There were at No. 6 shaft 17, and at No. 6 slope 15 mules, costing, on an average, $126.64 each, or $4052 for the two lots.

Operating-Expense by Mules.—The expense of operating with mules would be as follows:

	1897 (179 days).		1898 (160 days).	
	Per day.	Per year.	Per day.	Per year.
No. 6 shaft.				
Depreciation and interest on 17 mules, 25 per cent.	$3.01	$538.22	$3.36	$538.22
Feeding, attendance, harness and repairs, $141.40 per mule	13.43	2,403.80	15.02	2,403.80
6 drivers	9.40	1,682.60	9.40	1,504.00
6 couplers and spragmen	8.10	1,449.90	8.10	1,296.00
Total cost by mules	$33.94	$6,074.52	$35.88	$5,742.02
Cost by motor	11.12	1,989.69	12.00	1,921.77
Saving by compressed air	$22.82	$4,084.83	$23.88	$3,820.25
No. 6 slope.				
Depreciation and interest on 15 mules, 25 per cent.	$2.65	$474.90	$2.97	$474.90
Feeding, attendance, harness and repairs, $141.40 per mule	11.85	2,121.06	13.26	2,121.06
5 drivers	8.00	1,432.00	8.00	1,280.00
5 couplers and spragmen	6.85	1,226.15	6.85	1,096.00
Total cost by mules	$29.35	$5,254.11	$31.08	$4,971.96
Cost by motor	11.12	1,989.69	12.00	1,921.77
Saving by compressed air	$18.23	$3,264.42	$19.08	$3,050.19
Both No. 6 shaft and No. 6 slope.				
Total cost by mules	$63.29	$11,328.63	$66.96	$10,713.98
Total cost by motors	22.23	3,979.38	24.01	3,843.53
Saving by compressed air	$41.06	$7,348.25	$42.95	$6,870.45
Total saving in two years,				$14,218.70
Total cost of plant,				15,156.00

At the average rate of saving for 1897 and 1898, the entire cost of the plant would be saved in 361 working-days.

The capacity of the shaft-motor is equal to fully double its present work, and the slope-motor is working at but about one-third of its capacity, while the compressor is doing all that it can, and a second one was ordered April 7, 1900. To operate the plant to the full capacity of both compressors, which, under

Cost Per Ton-Mile by Mules.

	1897. Tonnage.			1898. Tonnage.		
	Ton-Mileage.	Cost.	Cost per Ton-Mile.	Ton Mileage.	Cost.	Cost per Ton-Mile.
			Cents.			Cents.
No. 6 shaft.						
Gross	1485	$33.94	2.29	1527	$35.88	2.35
Net	825	"	4.11	845	"	4.25
No. 6 slope						
Gross	648	29.35	4.53	720	31.08	4.32
Net	360	"	8.15	400	"	7.77
Total, gross	2133	63.29	2.98	2241	66.96	2.98
net	1185	"	5.34	1245	"	5.38

the present conditions, would be about 4500 ton-miles gross or 2500 net per day for 300 days per year, would bring the cost of operation, including fixed charges, to about $24.60 per day, or $\frac{6.47}{100}$ of a cent per ton-mile gross and $\frac{9.84}{1000}$ of a cent per ton-mile net load. If all the work could be done by one motor under the conditions of No. 6 shaft, up to the capacity of the compressor, for 300 days per year, using only one crew, the cost of plant would approximate $11,000, and the operating expenses, including fixed charges, would be $10.86 per day for 2400 gross ton-miles, or $\frac{4.8}{100}$ of a cent per gross ton-mile and $\frac{8.1}{100}$ of a cent per net ton-mile.

A further reduction of cost would result from re-heating the air at the motor, by passing it through water at the temperature of steam at 90 pounds pressure, by which method tests have shown a gain of about 50 per cent. in air-economy. It is probable that by this means one motor could be run to its full capacity (about 3000 gross ton-miles per day) with one compressor, at a total cost of $10.80 per day, or $\frac{3.6}{100}$ of a cent per gross ton-mile, for 300 days' work per year, the saving of $\frac{1}{10}$ of a cent per gross ton-mile, or about 20 per cent. over the last-mentioned conditions being due only to the greater air-economy; the fixed charges and labor-cost remaining practically the same.

For a detailed description of this plant, with illustrations, those who are specially interested are referred to the *Colliery Engineer and Metal Miner*, Scranton, Pa., for May, 1896, and to the Report for 1895 of the *Pennsylvania Bureau of Mines*, pp. 104 to 110.

STREET RAILWAY JOURNAL.

SEPTEMBER 29, 1900.]

Compressed Air Motors

BY H. D. COOKE

Compressed air for street railway operation is the subject assigned to me for treatment in this paper, and I find it difficult to place all the facts for an intelligent consideration of this subject before this convention in the twelve minutes allotted.

The question of liquid air was also coupled with this subject, but I do not deem it necessary to touch on this question more than to say that nothing has yet been accomplished in the manufacture of liquid air which will warrant its consideration as a factor in the operation of street railways at this time. The present method of its production is to start with compressed air at 2000 lbs. pressure, and by expanding many volumes of air at this pressure, thereby producing intense cold, to liquify a small volume of air. The only advantage which liquid air has is the small form in which it can be stored, 800 ft. being compressed into one, but, on the other hand, as in this form it is the ice of air, the additional cost of heat necessary to return it to ordinary air for use in cylinders, adds unnecessary expense. In other words, you cannot get out of a thing more than you put in it, and the expense in this case is prohibitive.

The subject-matter of our theme, therefore, will be confined to the latest and most improved compressed air cars now in actual service in three cities of the United States, which are started, kept running and stopped by compressed air. When it is considered that one of the earliest applications of air in railway service was its use for air brakes as a stopper of trains, it is passing strange that its use as a starter and operator of trains did not earlier occur to mechanical minds.

Space precludes any general review of the past history of air except to state that it was one of the earliest known of what may be termed the secondary forces or powers. Authentic records of the application of air are found among the writings of the Alexandrians, 300 years before Christ, and, later, water was used in connection with steam, but not much progress was made with either of these until the present century, during which such advances have been made in the manufacture of iron and steel, which have been used in the construction of engines, boilers, tubing, etc., as to make the use of steam the most important factor in modern life.

Although the application of compressed air to the propulsion of vehicles is of comparatively recent date, the fact that it is used in practically the same way as steam gives it the benefit of all that has been done in the way of the perfection of the steam engine. In fact, there are many instances where steam boilers have been charged with compressed air, and engines operated therefrom, and in one instance a locomotive was charged with compressed

air and run about the railroad yards and used for switching, etc. For such purposes, however, specially designed machines are better.

Limited space precludes any but the most general review of this important subject, and certainly nothing is more important to street railways than the question of a power which can be economically applied to all conditions of service, and which is of so simple a character as to make its operation and maintenance equally economical. Recently, however, it has been given serious consideration, and all the claims made for it have been fulfilled. It has proved itself reliable, unchanging, and where it has once performed a service it has always, under the same conditions, continued to perform that service. Unlike steam, compressed air does not have to be used as it is generated. It can be stored up, and is ready for use when needed. Compressed to any required degree, it will always return to its normal atmospheric density.

Briefly described, the construction and operation of an air car is as follows:

The most approved form of motor now in use in this country, and of which a number have just been constructed for the Metropolitan Street Railway Company, of New York, for its crosstown lines, consists of two small reciprocating engines underneath the car body, each connected directly to one pair of the car wheels, according to the most approved form of locomotive engineering practice. The pair of wheels so driven is connected by parallel connecting rods to the other pair of wheels, thus making all the wheels under the car drivers. The air, before passing into the cylinders of the engine, passes through a reheating tank of water, heated to an initial temperature of 300 degs. The reheating of the air before use returns to it all, or a very great portion of, the heat units which were taken from it during compression. To illustrate this, a test was made of a motor in Rome, N. Y. This motor, which carried 35 cu. ft. of storage, was run with cold air, until all the air was exhausted, and covered only 8 miles. Afterward, the same motor was run, using the reheating apparatus, and 15 miles were covered. The heating of the water in the tank is done by attaching a steam connection directly from the boilers which furnish steam to the compressors, to the reheating tank on the motor, and passing the live steam into the water.

In order that the minimum amount of difficulty might be experienced by the average motorman, a controller was devised, which, in appearance and operation, is very like an electric controller. An air brake is one of the features of these motors, and an ingenious contrivance in the way of a starter, is also controlled by the brake handle. The valve motion is exceedingly simple, and gives a range of cut-off of from 1-10th to 5/8ths of a stroke. There is no appreciable exhaust, and the operation of the motors is practically noiseless. The air brake used on these motors is operated from air stored on the car, and is absolutely noiseless, both in its application and release. Being operated by the same handle which starts the car, there is no danger of the motorman leaving his brake on and trying to start the car at the same time.

Cars of this type are in their sixteenth month of operation on the North Clark Street cable line in Chicago, doing the night or owl service on that line, and sometimes hauling two trail cars. During the severe winter weather and snow storms which prevailed in that city last winter the compressed air cars were the only ones to periorm their regular schedule. Compressed air cars have been in use in France for several years, and also in Switzerland, and in some places in those countries are used to haul two and three trail cars, but the American motors are pronounced by both our own engineers, and engineers from other countries, to be far superior to those of European manufacture.

The storage tubes under the car are of mild steel, capable of withstanding a pressure of 5000 lbs. to the square inch. Bottles of this character are used, both in the power house and on the car; the initial pressure in the power house being about 2500 lbs., and on the cars about 2000 lbs., which pressure on the cars is, by means of a reducing valve, reduced down to about 150 lbs. to the square inch before going through the reheating tank, and thence passing into the cylinders. It will be seen, therefore, that there is a ample factor of safety allowed by the storage tubes, and all precautions which can be are provided. It is apparent that the farther the cars travel the greater the factor of safety becomes.

The storage on the car is underneath the seats, or the car floor, and the cars, in appearance, resemble the standard Broadway, New York, cars, none of the storage or machinery being in sight, and no paying space being taken up by either.

We now come to the power house: Air compressors, driven by an economical stationary steam engine, or by water or other power, compress the air from atmospheric to 2500 lbs. pressure to the square inch, and as the air is compressed, it is stored in a battery of steel bottles of the character of those above mentioned. During compression, however, great heat is developed, and a system of water jacketing is used which reduces the temperature of the air to that of the surrounding atmosphere. By means of a special separator all the moisture contained in the air is separated from the air as it passes from the compressor to the storage, thus securing perfectly dry air. It is well known that expanding gas or air develops an exceedingly low temperature, but the use of the separator, removing all water from the air before storage, obviates freezing upon expansion, and the passing of the air through the hot water before use in the working cylinders restores to the air the heat units which were taken from it during compression, and also furnishes enough moisture in the form of steam to assist in lubricating the cylinders. The exhaust from the engine cylinders never falls below 70 degs.

In order to recharge the storage on the car it is only necessary to connect the storage in the power house with that on the car, and equalize the pressure between the two. This is usually done at the end of a run, and while the car is waiting, and takes about two minutes. In Chicago, however, this is done on the street, and while the car is on its route, and has never caused any delay or stoppage of the service, even though done while the air cars were running between cable trains.

During the last four years experimental and actual demonstration of air cars in the service have reasonably determined the following facts, viz.:

That the cars operated in Chicago during a period of six months consumed an average of 409 cu. ft. of free air per car mile, and that the cost of maintenance of these motors is much less than that of the ordinary steam engine, as there is no boiler to be cared for.

We have been furnished figures by the most responsible builders of air compressors in this country, estimating on a volume of 6800 cu. ft. of free air per minute, which should be sufficient to operate one hundred cars, which show that 2.8 cents will compress 1000 cu. ft. of free air to 2000 lbs. pressure. This estimate is approximate for local conditions, and coal is figured at $2.90 per ton for a twenty-four hours' service, taking 2 lbs. per hour for indicated horse power. This includes attendance of engineers, helpers, firemen and laborers, and also for oil and waste, and allows for 10 per cent per annum for depreciation.

It is believed that compressed air cars have a place in every large system already installed, whether cable or electric, either for performing night service where it is not advisable or economical to run a large plant for the operation of a small number of cars, or where feeder or crosstown lines are necessary, and the installation of the overhead or underground trolley would not be permitted.

In brief, the advantages of compressed air for the operation of street railways may be summed up as follows, viz.:

1. A system of independent motors, which, after receiving their charges, do not rely upon the power plant, and which will always finish their run, should anything happen to the power plant; which also do not need any special outdoor construction, either underground or overhead, with the attendant cost of maintenance.

2. Slow moving machinery, both in the power house and on the car, which is easily maintained.

3. Opportunity for charging cars, and storage in power house, during light hours, for use during the rush hours.

4. Spring-supported motors and load, doing away with excessive jarring and pounding on the track, and thus greatly prolonging the life of the roadbed, the life of the motors, and contributing to the easy riding of the cars.

5. Low first cost of plant; low cost of maintenance, and opportunity for making repairs and adjustment without stopping operation of cars.

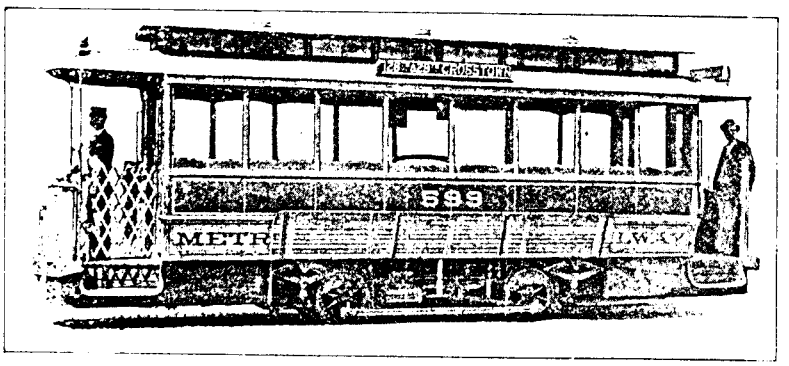
6. Freedom from liability of delay in transit from snow, ice or sleet.

STREET RAILWAY JOURNAL.

OCTOBER 13, 1900.]

Compressed Air Cars in New York

The new type of compressed air cars being used by the Metropolitan Street Railway Company, of New York, and manufactured by the Compressed Air Company, under the Hardie patents, have been put in operation on the Twenty-Eighth and Twenty-Ninth Streets line. The cars differ considerably in appearance from



AIR MOTOR CAR IN NEW YORK

those formerly used, as will be seen from the engraving herewith. The chief feature of difference to the ordinary observer is the use of connecting rods. The motors, however, as well as the general method of using the air, is quite different from that formerly employed, as was fully described in the STREET RAILWAY JOURNAL for August.

In actual service on the street a wooden screen, shown raised in the cut, covers the upper part of the truck and connecting rod, this having been considered more desirable for city service

SRJ 1900 vol xvi no. 51

The Operation of Compressed Air Cars in New York City

The Metropolitan Street Railway Company took formal control of the cars, charging station, etc., of the Twenty-Eighth Street and Twenty-Ninth Street line on Dec. 6. The Hardie system has been used on this line since Sept. 26, and the compressed air company which controls this system has been operating the cars. A great amount of data regarding the running expenses, speed, capacity of the reservoirs, etc., have been collected during the three months that the cars have been running, which has been carefully compiled, and much interesting information obtained. From Sept. 26 to Dec. 16 the cars traveled 139,057 miles and carried 1,496,287 passengers, the maximum number of cars operated at any one time being twenty. Careful records were kept of each of the 25,283 trips, and from them the following estimations were made: Repairs, including material, supervision, machinists and workmen, adjusting valves, piping, repairing brakes, rods, brasses, etc., $35 per day, or 2 cents per car mile. Charging expenses, including oil, waste, foremen, charging gang (two shifts), oilers, cleaners, etc., $28 per day, or 1.60 cents per car mile. Power house expenses, including engineers, coal passers, firemen, oilers, pipe fitter, machinist, etc., 16 tons coal per day, oil, waste, etc., $82.50 per day, or 4.71 cents per car mile. These figures are made on a basis of 1750 miles per day, with the present equipment of twenty cars. With the same charging and power plant, however, and but little increase in cost of coal and labor, from sixty cars to eighty cars could be operated. The length of the round trip is 5½ miles, and two trips can be made on one charge. In fact, 15 miles has been covered without recharging, but this is rather too much for ordinary practice with the reservoir capacity installed.

The immense cost of conduit construction on the crosstown lines in New York renders some self-contained method of propulsion a necessity. From the above figures it would appear that the Hardie system may prove a satisfactory solution to the problem.

SRJ 1901 vol. xvii no. 15

Compressed Air Cars in New York

The compressed air cars which have been in operation on Twenty-Eighth and Twenty-Ninth Streets for several months past have been withdrawn and the old horse cars substituted. The traffic on this line has increased enormously since the introduction of the compressed air cars, being far beyond the anticipations of either the railway company or the makers of the motors. The requirements of the service, have, therefore, proved too great for the capacity of the motors, and the cars have been withdrawn in order that larger equipments, which are now in course of construction, may be substituted for the ones which have been found inadequate. During the six months in which these cars have been in regular service, the twenty cars on the line have carried over 3,000,000 people, and the rough handling which is incidental to the operation of all unfamiliar mechanisms, as well as the excessively severe service, has rendered it advisable to temporarily suspend the service. It is expected that by May 1 the new equipments will have arrived and that the service will then be reinstated on a more satisfactory basis.

STREET RAILWAY JOURNAL.

MAY 11, 1901.]

Compressed Air Accident

NEW YORK, April 30, 1901.

EDITORS STREET RAILWAY JOURNAL:

I send you herewith copy of letter written me yesterday by Col. Ashley W. Cole, chairman of the State Board of Railroad Commissioners of the State of New York, in regard to the breaking of the reheating cylinder on Car No. 502, on Twenty-Fourth Street, on March 29. The report from which he quotes is a complete vindication of air in this matter, the newspaper accounts of which were so grossly exaggerated. This car was in service the next day, with a new reheating cylinder, with the pipe referred to specially held on brackets in the center of the cylinder in a manner to absolutely prevent the possibility of a recurrence of the accident.

This car was one of twenty which were operated for six months and two weeks on Twenty-Eighth Street and Twenty-Ninth Street, this city, during which time they carried 3,250,829 passengers, and on the last day of service these cars carried an average of more than 1100 passengers per car, one carrying as high as 1673 passengers, another 1566 passengers, another 1486 passengers, etc.

Air cars have been performing the night service on the North Clark Street line of the Union Traction Company in Chicago for over two years, and are still running, and giving good satisfaction. The street car system of Rome, N. Y., is entirely operated by air cars, and air cars were successfully operated on 125th Street this city, for one year. HENRY D. COOK, President.

[COPY OF LETTER]

STATE OF NEW YORK,
BOARD OF RAILROAD COMMISSIONERS,
ALBANY, N. Y., April 29, 1901.

HENRY D. COOK,
President Compressed Air Company, New York City.

Dear Sir.—Referring to your letter of inquiry concerning the accident on Twenty-Fourth Street, on March 29, would say that this was caused by the bursting of the reheater cylinder, as will be seen from the following extracts from the report of the steam and electrical experts of the Board of Railroad Commissioners:

"The accident which occurred on car No. 592 was caused by the bursting of the reheater cylinder. * * *

"This was undoubtedly due to the lower perforated pipe in the cylinder becoming broken from its fastenings and lying loose on the bottom of the cylinder, and oscillating on the plate of the cylinder. The oscillation was caused by the motion of the car and the action of the air entering the cylinder. A groove had been worn in the steel plate of the cylinder as perfect and true as though done by a tool, reducing the thickness of the middle of the cylinder to less than 1-16 in. * * *

"It will be seen from the above description of the operation of compressed air as a motor power for street surface cars, that this was not an explosion caused by compressed air under high pressure contained in the reservoirs on the car, but was the fracture of a reservoir containing hot water and compressed air at a pressure of not more than 150 lbs. to the square inch.

"(Signed) ASHLEY W. COLE, Chairman."

STREET RAILWAY JOURNAL.

DECEMBER 28, 1901.]

Compressed Air Car Operation

Some very interesting results are shown in a statement of operating figures, made by the Rome (N. Y.) City Street Railway. Compressed air cars, made by the Compressed Air Company, New York, have been operated on this line with great success, although the traffic conditions of the city are such that the present plant is not giving the most economical service. With one-third more mileage required no additional expense would be incurred, except a slight increase in coal consumption. The statement recently compiled and given below contains a record of the cars for November, 1901, during which month traffic was suspended for two days on account of the condition of the bridges over the canal.

OPERATION OF COMPRESSED AIR CARS,
ROME, N. Y., NOVEMBER, 1901.

CAR No. 105; 78 CU. FT. STORAGE; AIR BRAKE

Number of days in service	28
Number of miles run	2,743
Average miles per day	98
Average feet of free air per mile	737

CAR No. 108; 73 CU. FT. STORAGE; AIR BRAKE

Number of days in service	28
Number of miles run	2,436
Average miles per day	87
Average feet of free air per mile	641

CAR No. 575; 78 CU. FT. STORAGE; AIR BRAKE

Number of days in service	28
Number of miles run	2,560
Average miles per day	91
Average feet of free air per mile	727

CAR No. 578; 78 CU. FT. STORAGE; HAND BRAKE

Number of days in service	26
Number of miles run	2,282
Average miles per day	88
Average feet of free air per mile	711

During the month the general average per car mile for all cars was 704 cu. ft. of free air.

Total cost of operation of, and repairs to power plant and cars, exclusive of motormen and conductors	$951.99
Cost per car mile, free air consumed, including all expenses	.08 2
Cost of repairs per car mile	.01 3
Total cost of operation	.09 5

HORSELESS VEHICLES

AUTOMOBILES

MOTOR CYCLES

OPERATED BY

STEAM, HYDRO-CARBON, ELECTRIC AND PNEUMATIC MOTORS

BY

GARDNER D. HISCOX, M.E.

AUTHOR OF

"GAS, GASOLINE AND OIL ENGINES"

AND

"MECHANICAL MOVEMENTS, POWERS, DEVICES AND APPLIANCES"

1901

CHAPTER XVI.

COMPRESSED AIR POWER FOR VEHICLES.

The use of compressed air for railway propulsion has now been on trial for nearly a quarter of a century, with but small advances in its adaptability beyond the limited terminals of local road lines, and for factory and mining traction.

The bar to its early success seems to have been wholly due to the initial low pressure in the storage tanks, which was limited to from 350 to 600 pounds per square inch, until the beginning of the last decade, when high pressure air service, for motive power, began to receive attention. The first trials of compressed air at from 2,000 to 3,000 pounds pressure per square inch was in railway work, and has reached a successful issue.

The first trials of high pressures for road carriages did not give satisfactory results in England, but its application as a motive power for heavy vehicles has made a fair progress, and is now in successful operation in France. A delivery wagon is reported to be in operation in Paris, having a storage capacity of 18 cubic feet of compressed air at a pressure of 4,200 pounds per square inch.

The air is delivered from the high pressure steel bottles by a differential valve, and reheated in a steel coil by a gasoline burner to an amount to double its volume under a varying working pressure of from 25 to 50 pounds per square inch, as needed. The cost of reheating the air for this vehicle is about one pound of gasoline per hour, when running at ordinary speed.

In the United States, the American Air Power Company, the International Air Power Company, and the New York Auto Truck Company are pushing the interest of compressed air for vehicle propulsion with a line of practical experiments to demonstrate the feasibility of compressed air vehicles for street haulage and for ordinary truckage. These companies are operating under the Hardie and Hoadley-Knight patents.

A runabout wagon has been constructed by Mr. C. D. P. Gibson for the Air Vehicle Company, with an air engine weighing but 36 pounds, and with compressed air storage capacity of six cubic feet at 2,500 pounds pressure per square inch, the vehicle, storage and motive power weighing 670 pounds. The working pressure is reduced to 150 pounds through a differential valve, and the air reheated. Thus, a

single storage charge should give out one horse power for five hours, and cover a distance of from 20 to 30 miles in such a vehicle. Thus the possibilities of compressed air for individual use lie in the ability to obtain a charge at some high pressure air station, or to operate a small oil engine power and high pressure compressor with, perhaps, a high pressure reserve tank for contingencies.

For trucks or traction wagons operating on short circuits, the problem of the practicable service of compressed air for vehicle power is most encouraging. For shop and yard work requiring short circuits with facilities for recharging at several points from pipe-line air hydrants, the problem has been practically solved: and we illustrate in Fig. 267 a shop truck built by and operated in the works of the American Wheelock Engine Company, Worcester, Mass. The upper hand wheel is on the steering spindle; the lower hand wheel is for operating the motive power by a lanyard connection to the link valve gear. The throttle is governed by a lever which is opened by the operator pressing his knee against it and is closed by a spring. The motor drives both rear wheels through a differential gear, and, when working under ordinary conditions, uses about 75 cubic feet of free air per mile.

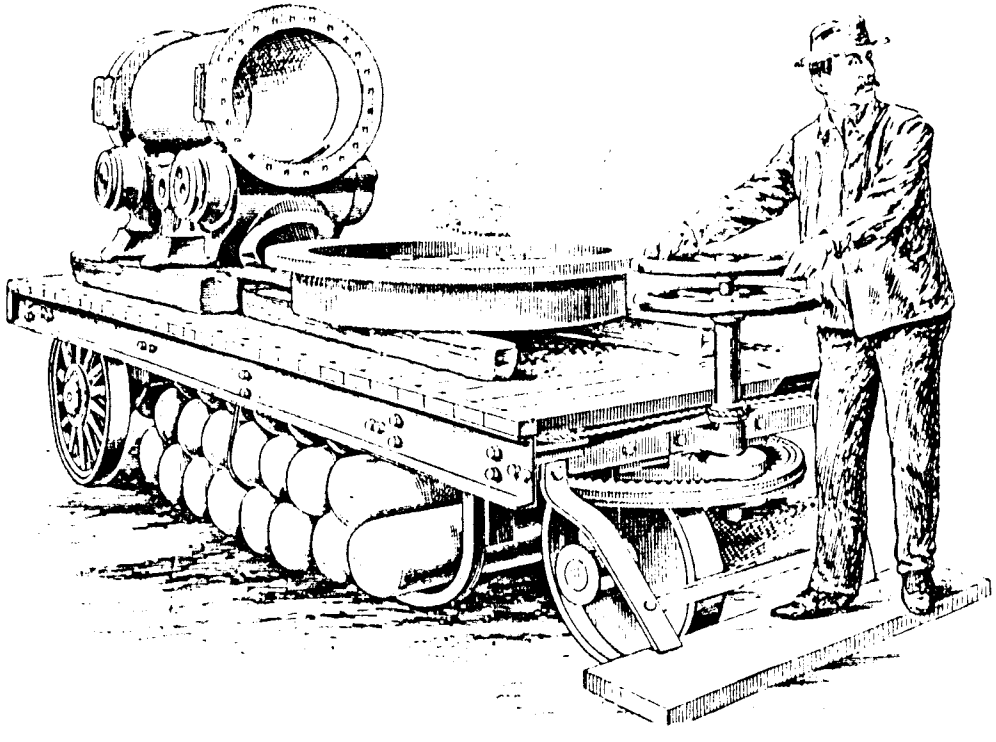


Fig. 267.—Compressed Air Shop Truck.

It will move a load of ten tons, and occupies a space of 4 feet wide by 15 feet long.

Fig. 268 illustrates a truck for general haulage used at the Worcester works for shipping machinery and hauling supplies. In this truck the air is reheated by passing through a hot water tank charged to a high pressure.

In Fig. 269 is illustrated the same kind of truck loaded with lumber and in use in New York City, and in Fig. 270 a compressed air traction wagon hauling a coal wagon.

In Fig. 271 is illustrated the same traction wagon hauling a flat car loaded with machinery from the works, acting the part of a switching engine.

Fig. 272 is an ideal diagram of the operating parts of a

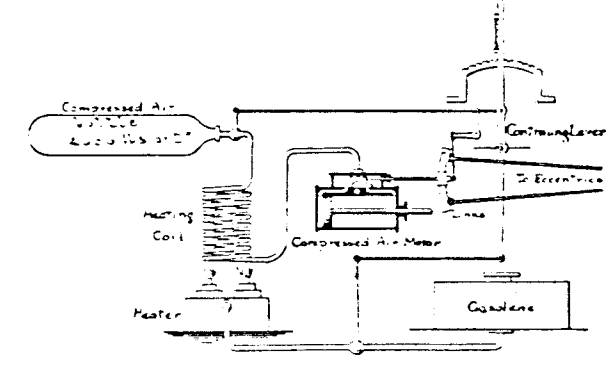


Fig. 272.—The Reheating of Compressed Air when Cooled by Expansion from High Pressure Storage.

compressed air motor [illegible] with the following [illegible]
Compressed air trucks and tract[illegible] wagons are also [illegible] at the works of the International Power Company, Providence R. I.

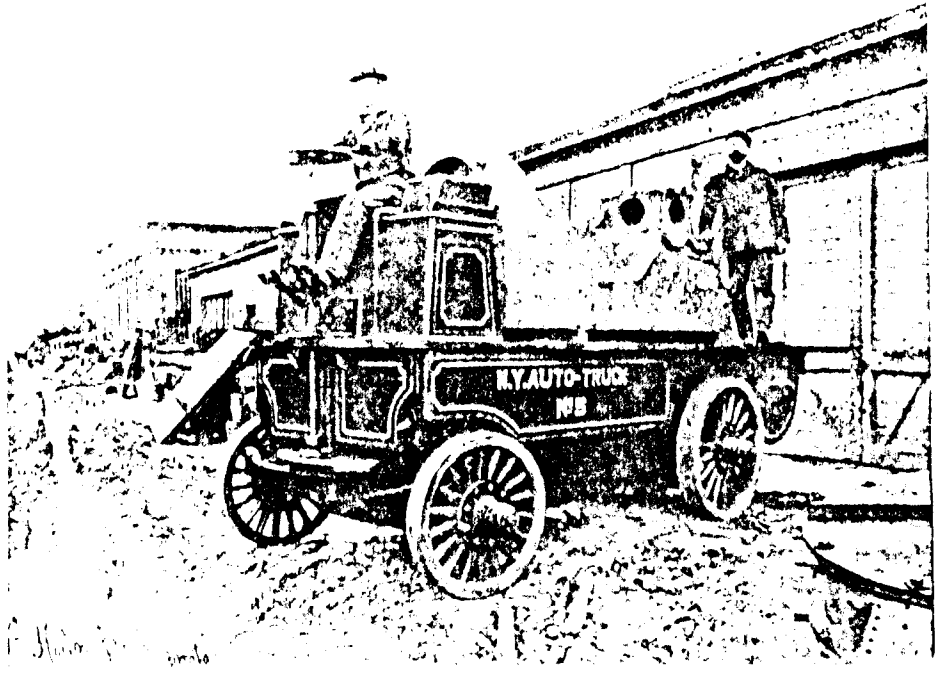


Fig. 268.—A Compressed Air Street Truck

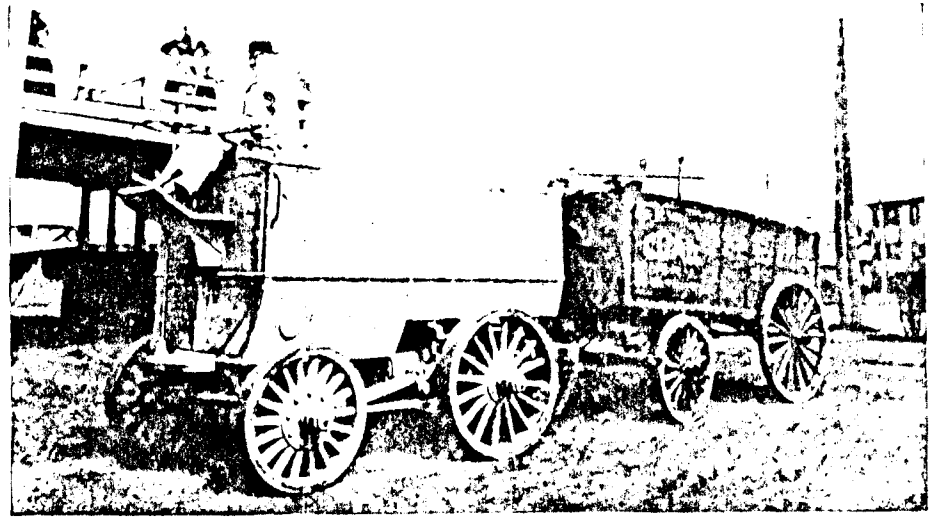


Fig. 270.—A Compressed Air Traction Truck with a Trailing Coal Wagon.

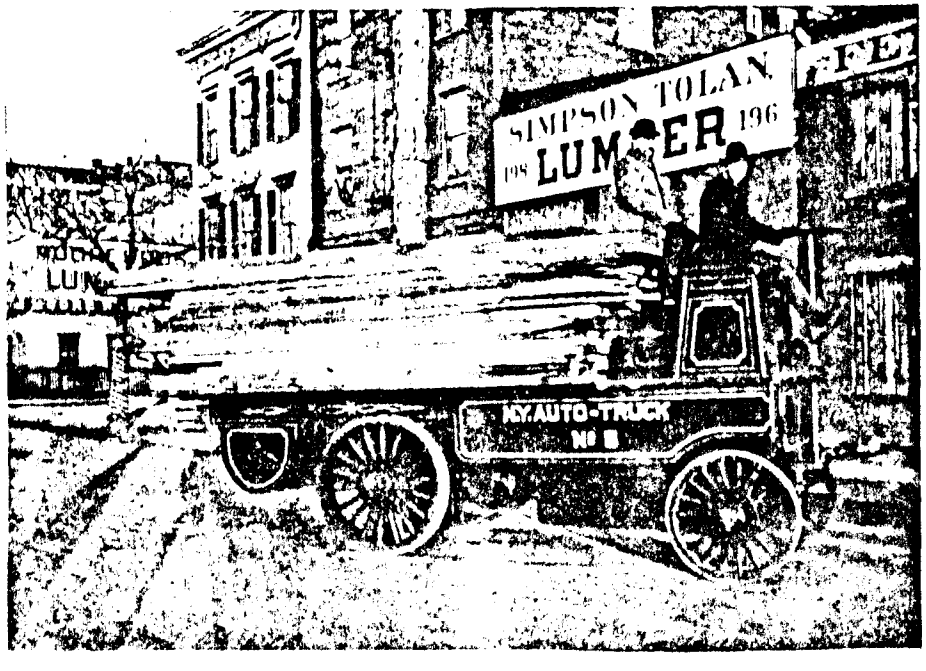


Fig. 269.—A Compressed Air Street Truck Under a Load of Lumber.

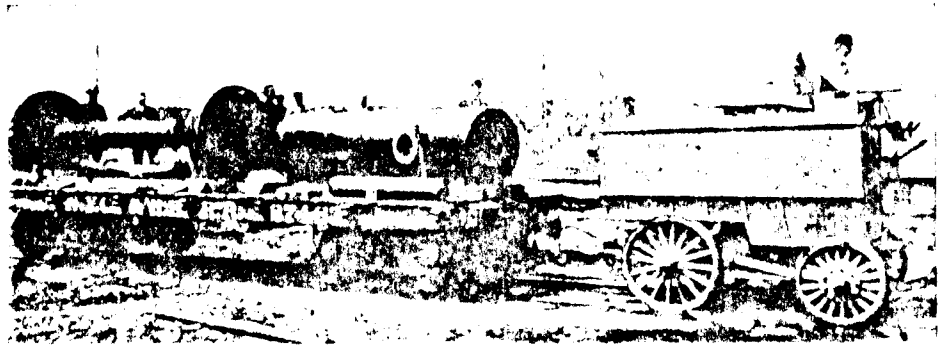


Fig. 271.—A Compressed Air Traction Truck Moving a Loaded Platform Car.

1902 Volume 22

COMPRESSED AIR IN MINING

FOR DRILLING, HAULING, HOISTING, AND PUMPING

By Edward A. Rix

COMPRESSED AIR FOR MINE HAULAGE

When the distances in a mine become great the cost of tramming ore and waste becomes quite an item. The length of time necessary for a round trip makes it difficult to handle the quantity, and man haulage gives way to a train of cars hauled by animals. Steam motors cannot be used, on account of their heat and smoke.

During the last ten years a great many mines have replaced animal haulage with compressed air motors, which lend themselves splendidly to the work desired. There are, in general, two sytems,—the low-pressure system, in which air is compressed to five or six hundred pounds; and the high-pressure system, with air pressures of 2000 pounds and over. The former system can be used in large galleries or tunnels or drifts where the width is ample and the track is reasonably straight. This permits a large receiver on the motor, 30 to 40 inches in diameter and from 8 to 16 feet long, to be handled with ease. The high-pressure system is used where the drifts are narrow or the curves on a small radius, permitting only a small wheel-base on the motor. Large receivers are, therefore, impractical, and steel tubes must be used and charged with high-pressure air to get sufficient volume.

Compressed air may be used cold on either of these motors, or the air may be passed to small tanks of hot water supplied to the motor at the charging stations.

The air and hot water combination does almost double the work that cold air will do. These motors can carry sufficient air for any ordinary run desired and haul tremendous loads. Two miles and return, with fifteen or twenty loaded cars, is not an extraordinary effort, and from the general results obtained, the cost of haulage is from one-half to one-third of the cost of the animal power. The air escaping from the exhaust of the motor engines adds to the ventilating effect in the mine and the whole system harmonises thoroughly with the power outfit in the average mine.

During the year 1900 the writer was given the opportunity at the Morning Mine, at Mullan, Idaho, U. S. A., of installing upon their property a typical modern mining plant and one which contains most of the salient features that are considered important in compressed air engineering. A brief description of the plant, which, aside from being interesting from a compressed air standpoint, employs now the largest tangential water-wheel in the world and shows how three different heads of water can be harmonised on one compressor shaft, may not be inappropriate here.

The considerable cost of fuel to operate the steam-power compressors at the mine determined the management to utilise the water-power in the neighbourhood to drive a compressor large enough for future needs. Surveys of possible water-power were made long ago, and eventually a site was determined upon near Mullan which made it possible to utilise three water-powers: first, that of the Cœur d'Alene River, by building a dam and headgates just below the Morning mill and carrying the water in a flume to Grouse Gulch, giving 140 feet of pressure; second, by taking up the headwaters of Grouse Gulch and conducting them to a favourable point so as to obtain a fall of 1420 feet; third, by similarly taking up the waters of St. Joe and Rock creeks and obtaining a head of 1140 feet. The total capacity of these three sources would give a minimum of 1100 horse-power during the season of the lowest stage of water.

The river flume is built of planed lumber, and battened inside and covered. It is 5 feet wide by 4 feet high in the clear and about 8000 feet long, delivering into a steel pipe 42 inches in diameter and 400 feet long, reaching to the power house. The Grouse Gulch pipe line is 7350 feet long, containing 2000 feet of 9-inch and 5350 feet of 8-inch standard pipe. The Rock Creek water-line consists of 2645 feet of 8-inch standard pipe. All of these lines are well anchored and completely buried.

The compressed air line consists of 9500 feet of 12½-inch inserted joint pipe, which reaches to what is known as Station No. 6. From there two 9-inch branches are made, one into the No. 6 tunnel, which, when completed, will be 10,200 feet long, and one branch of 9-inch pipe to No. 5, 11,700 feet long and into No. 5 tunnel 1500 feet, making a transmission of 22,700 feet to the present workings.

The compressor is designed to run 100 drills, and, owing to conditions relative to power, has offered a very interesting problem in compressor construction. On the main shaft of the compressor is mounted, as previously stated, the largest tangential water-wheel in the world, being about 33 feet in diameter.* The rim is made very

* In addition to the illustrations of this plant on pages 347 and 348 of this article, it may be interesting to refer also to the elevation and plan given on pages 434 and 435 in the article on "Water Power in Mining," elsewhere in this issue.—THE EDITOR.

heavy to serve as a fly-wheel, and the diameter is a compromise between the requirements of the two higher heads, taking eighty revolutions of the wheel as the standard number of turns. This wheel will give the tremendous rim speed of more than 8000 feet per minute, which has required special construction of the highest grade.

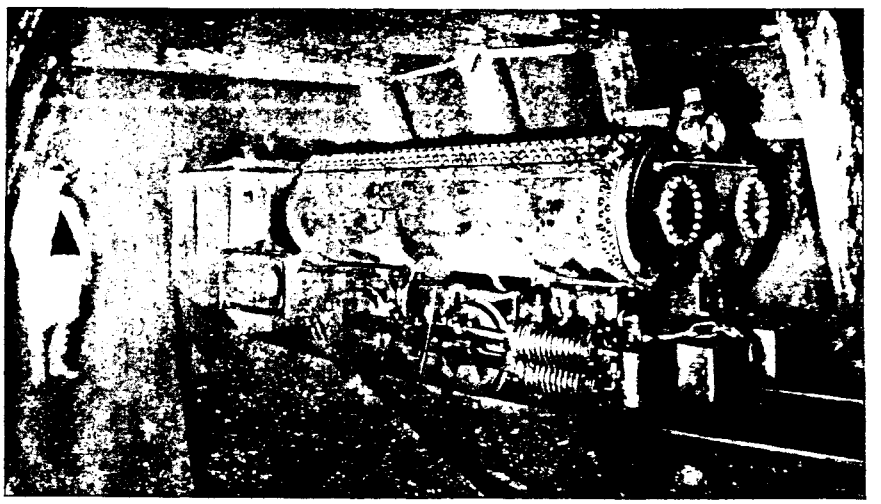
Two separate pipe lines convey the water to the nozzles at the periphery of the large wheel, and each nozzle is controlled by a suitable high-pressure gate valve and its by-pass, to prevent shock to the pipe line. The nozzles also have deflectors, so that the water streams may, in an emergency, be thrown from the wheel by the station operator. On the other side of the large wheel are two 11-foot Pelton wheels to receive the water from the Coeur d'Alene River, at a head of 140 feet, the total capacity of these two wheels being about 1200 H. P.

The compressors are compound, compressing the air in the first stage to twenty-five pounds and delivering it into the mains at ninety pounds, the heat generated by the first compression being absorbed in a double set of intercoolers placed in the tale-race of the low-pressure wheels. The compressor cylinders are, respectively, 32½ and 18 by 42 inches stroke, so that the piston speed of the compressor is 560 feet a minute, which is practically the limit of compressing speed. While this speed might not be disadvantageous to a single-stage compressor where the delivery occurs at or near the end of the stroke, in a compound compressor for the above pressures the delivery valve must open at about the centre of the stroke where the piston speed is 50 per cent. higher than the average. The delivery valves are thus compelled to open when the piston is moving at somewhat over 800 feet a minute. This presented a unique problem for valve construction, which has been solved in this instance by a very complete and satisfactory valve gear. All of the foundations are elaborate and expensive and are three separate stories in height They are pierced by tunnels, and will be lighted so that any portion may be inspected at any time.

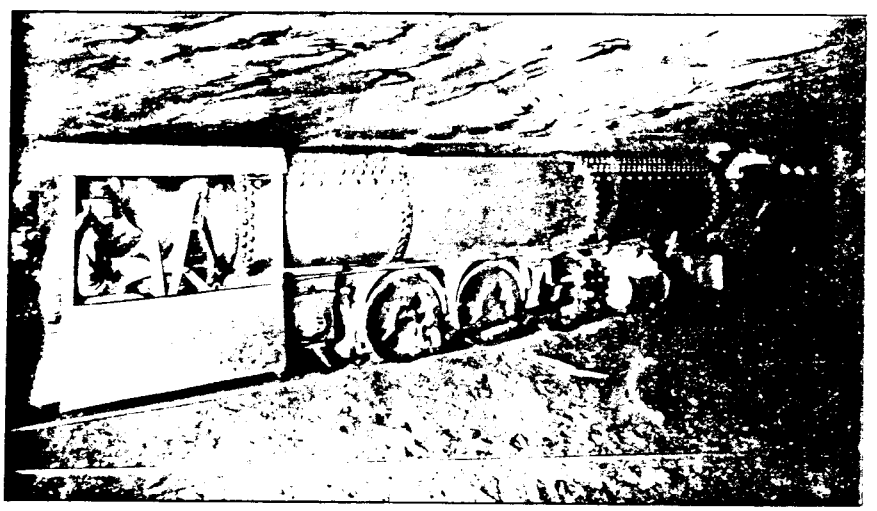
The intercooler is unique in character, and consists of a large number of 1¼-inch brass tubes, about 18 feet long, in a reservoir of water situated in the middle story of the foundations, flooded by backwater from the low-pressure wheels. Perforated floors under the intercoolers permit continual circulation, and are arranged to take away any sand which may be deposited.

The compressor is also fitted with an aftercooler, and underneath the cylinders and main frames a wide channel in the concrete is made, through which water continually flows to take away the immediate heat from the discharge valves, and to take away the discharge from the water circulations and also the oil and dust refuse. Each cylinder has two independent water circulations and each head has an independent water circulation. No expense has been spared to make this a thoroughly first-class and satisfactory installation.

The plant has realised all expectations. The temperatures in the compressor are remarkably low, indicating efficient working. The pipe line is perfect, and was tested to 160 pounds water pressure before turning in the air. It is seldom that a compressor has an opportunity to pump into so large a reservoir, namely, 12,000 cubic feet at present, but which will be, later, about 17,000 cubic feet. At present the reservoir holds 100,000 cubic feet of free air at ninety pounds pressure, or about 10,000 stored horse-power, calculated on the basis of a reheated economical motor. It will be interesting to those who are contemplating compressed air transmissions to know that the loss in this four-mile transmission may be neglected. The Morning Mine closed down the old compressors and found, upon turning in the new line that it took about 2000 cubic feet of free air to do their present work. This amount passing through the pipes showed no appreciable loss on the gauges. It was not one pound at the most.



A COMPRESSED AIR MINE LOCOMOTIVE BUILT BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA



A COMPRESSED AIR MINE LOCOMOTIVE BUILT BY THE H. K. PORTER CO., PITTSBURG, PA.

There appear to be six general forms of compressed air pumps:—First, displacement pumps for full pressure only; second, displacement pumps using expansion; third, direct-acting pumps for full pressure only; fourth, direct-acting

pumps using expansion, fifth, air lift pumps, simple and combined with displacement chambers; and sixth, pumps operated by independent motors.

In the first style of pump, illustrated by the Merrill type, two chambers are employed, submerged in the water, the compressed air being admitted directly to the chambers and displacing the water, the chambers acting alternately. With such a pump an efficiency of about 22 per cent. has been claimed, which is better than most ordinary direct-acting pumps will do with cold air. One can readily see, however, that this style of pump exhausts its chambers into the atmosphere at full pressure and all the expansive work contained in the air is lost. This system compounded, however, can be made very efficient.

In pumps of the second class, exemplified by the Harris system, the air, after displacing and raising the water as above, instead of being at once exhausted into the atmosphere is allowed to do work in expanding against the compressor piston, and thus, practically speaking, all its expansive energy is saved; but the manufacturers admit the losses in leakage and friction to be about 15 per cent. This is a very interesting and efficient system, and may be justly entitled to an efficiency of from 60 to 70 per cent. It should prove a very desirable system for mine station pumping.

In the third system we have a type of direct-acting pumps which are generally given a mechanical efficiency of 65 per cent. and an actual efficiency of from 15 to 22 per cent. They use the air at full pressure only. If a pump uses full pressure only, it is evident that the more full pressure a compressor diagram shows, the greater will be the efficiency of the system; the lower the air pressure, the less the compression work and the greater the proportion of full pressure work; consequently the lower the pressure, the more efficient the system. This really refers to the compressor and not to the pump, for the pump works the same whether it receives air at ten pounds pressure from the compressor, or whether it has been expanded from a receiver having a higher pressure, provided the temperatures are constant. If we look for the best efficiencies from the direct-acting pumps we must put in an independent compressed air system and carry low pressure.

The general conclusions in operating direct-acting pumps are as follows:—

First.—The lower air pressure in the main, with the cylinders designed properly, the greater the efficiency, reaching as high as 30 per cent.

Second.—The efficiency drops immediately if the air is expanded through the throttle into an air cylinder which requires less pressure than the main.

Third.—At standard mining pressure of ninety pounds the efficiency is about 17 per cent., with properly designed cylinders, and probably drops as low as 12½ in the pumps where just one turn of the valve is open.

Fourth.—Very little loss occurs in using pressures within 10 per cent. of the pressures in the main, which is ample to impart proper dynamic head to the pump. Compound compression will increase these efficiencies 15 per cent., and reheating will also increase the efficiencies in proportion to the ratios of the absolute temperatures.

Fifth.—Compound, direct-acting pumps are very little understood. The general idea has been that if the expansion of air produces such low pressures that it frequently freezes the simple pump, it would be an unwise proposition to try full expansion in compound pumps; consequently compressed air users practically avoid multi-cylinder pumps.

To use compound pumps the air must be heated in some manner. This reheating can be done either with the water which is being pumped, or extraneous heating before the initial cylinder, or extraneous heating before the compound cylinder, or extraneous heating before both cylinders. By reversing the idea of the intercooler in compression and passing the air from the initial cylinder of a compound pump through a series of coils around which the water that is being pumped circulates, the air will take on very nearly the temperature of the water, and it will be delivered to the second cylinder at practically the same temperature as the first, thus permitting a number of expansions to be used, and the efficiency of any ordinary compound pump may be made equal to from 37½ to 40 per cent. by this simple method of water reheating. In other words, almost double the water can be pumped for the same amount of air used in a simple pump.

Where extraneous heating is used before the initial cylinder and between the two cylinders, the efficiency in compound pumps may be made to vary from 30 to 72 per cent., a vastly greater efficiency than is generally thought possible.

The combination of displacement and air-lift pump may be noted in the Wheeler pneumatic pump.

The Cummings, or the two-pipe system, is a very interesting one, consisting of compressing the air to a high pressure,—about 200 pounds,—and exhausting it back from the pump at 100

pounds. This may be made to give an efficiency of probably 50 per cent., and if reheated, possibly more.

Air-lift pumping, or the Pohle system, as it is called, is a simple system, which consists in reducing the specific gravity of water in the pipe by admixture of air, so that the head of water on the outside of the pipe will push it out. Extensive experiments have been made with it in America and in Germany, and it may be assumed that the efficiency may reach as high as, say, 50 and 60 per cent.

Motor-operated pumps consist of pumps belted or geared or directly connected to all kinds of engines. There is no doubt that with Corliss engines coupled directly to pumps, and properly reheated and compounded, the efficiency will reach somewhere about 75 per cent.

In conclusion, the efficiencies on the next page are suggested. The percentages given in the table there may be taken as fairly accurate in comparing the various kinds of pumps, and the relations between them will be properly expressed by these figures, even if the actual efficiencies, as determined by other observers, may be somewhat different.

In explanation of the following table, the writer would say that the figures are on the basis of a pressure in the air mains of ninety pounds gauge. By foot-gallons is meant the product of the number of gallons pumped and the feet elevation that the water is pumped. This I find to be the most convenient and reliable way to designate the duty of pumps, and the foot-gallons designated are the work of one cubic foot of free air compressed to ninety pounds gauge pressure.

90 Lbs. Air Pressure on Main

Kind of Pump	Foot Gallons	Efficiency Simple Comp.	Efficiency Compound
1. Direct-acting simple	135	17	20
2. Direct-acting simple 300 reheated	181	24	28
3. Direct-acting compound, water reheated	232	32	375
4. Direct-acting compound, 1 cyl. heated	283	40	46
5. Direct-acting compound, 2 cyl. heated	327	47	53
6. Direct-acting triple cyl. heated	383	54	62
7. Direct-acting triple cylinder heated	444	63	72
8. Pohle displacement	175	22	25
9. Wheeler displacement, 34 per cent for 34 lbs pressure	...	..	.
10. Multiple displacement	320	40	46
11. Harris displacement	60 to 70 p. c.		
12. Merrill displacement	175	22	25
13. Cummings system	35 to 70 p. c.		
14. Compound motor pumps	50 to 80 p. c.		
15. Direct-acting triple water-heated	300	42	48
16. Pohle air lift, 50 to 60 per cent heads less than 500 feet	...	..	..

The second column shows the efficiency of the system with ordinary single-stage compressors and the third column with compound compressors.

No. 1 is the plain, direct-acting pump, like a plain boiler feed pump, and the table shows that one cubic foot of free air, compressed to ninety pounds gauge pressure, will perform 135 foot-gallons of work; that is to say, it will lift one gallon 135 feet, or ten gallons 13.5 feet, and so on.

No. 2 shows that the above pump will perform 180 foot-gallons of work if the air is heated to 300 degrees before entering the pump.

No. 3 shows that an ordinary direct-acting compound pump, using the water that is being pumped to heat the air on its way from the high to the low-pressure cylinder, will perform 232 foot-gallons of work, giving thus almost double the efficiency of No. 1, and requiring no fire heating,—simply a little more investment in the installation.

No. 4 is the same kind of pump as No. 3, heated by fire to 300 degrees between high and low-pressure cylinder instead of utilising the heat of the water. It is more economical, but the utility is not so high.

No. 5 is same pump as Nos. 3 and 4, but is fire-heated to 300 degrees before and after the high-pressure cylinder.

No. 6 is a triple-cylinder pump heated before and after the high pressure and after the intermediate to 300 degrees, giving 383 foot gallons.

No. 7 is same pump heated to 400 degrees, giving 444 foot-gallons, showing that the same air as in No. 1, giving 19 per cent., can be made to give 63 per cent. properly manipulated.

No. 8 is a plain displacement tank, showing that it is more economical than an ordinary direct-acting pump.

No. 9, the Wheeler displacement pump, which is an ordinary tank displacement and an air lift combined, gives 34 per cent. efficiency.

No. 10 is a multiple displacement proposition where the displacement tanks are arranged above one another at distances corresponding to the ratios of isothermal expansion, giving a calculated efficiency of 40 per cent.

No. 11, the Harris system, where, after displacement in a tank, the air is returned through the compressor to the other tank operating in harmony with the first, is the most economical way of handling water by compressed air that the writer has seen.

No. 12, the Merrill displacement system, is a plain displacement system of two tanks.

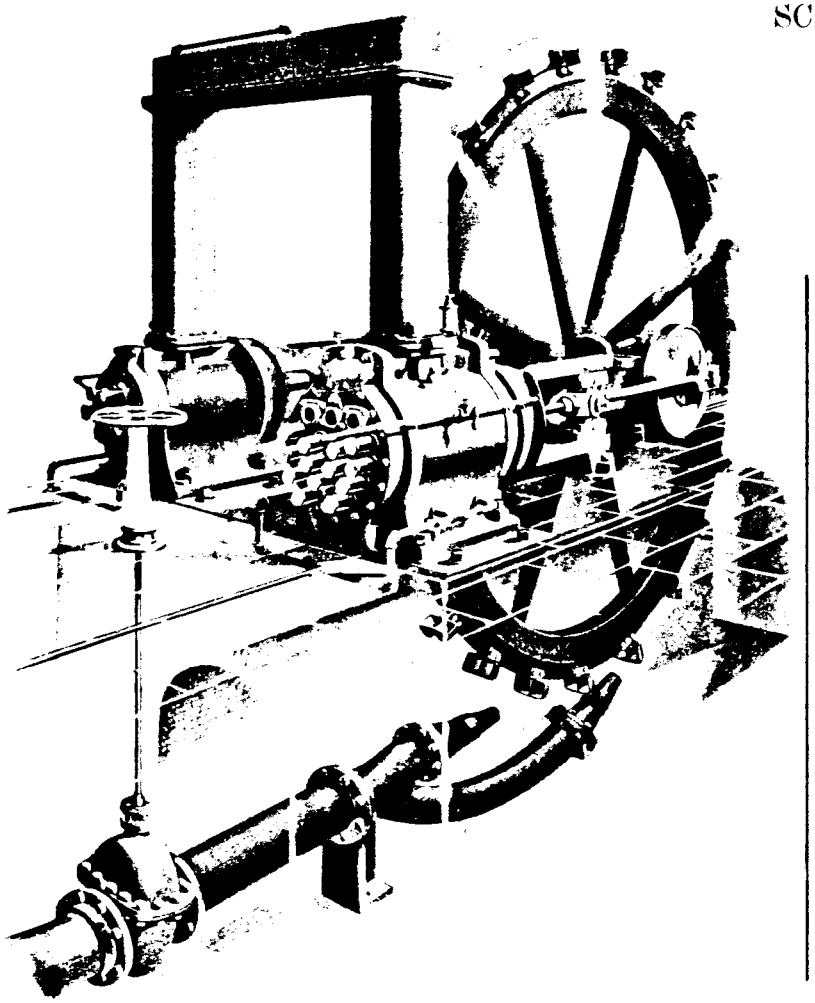
No. 13, the Cummings system, which is used in connection with direct-acting pumps, is a two-pipe or closed system,

delivering air to the pump at about 200 pounds per square inch and exhausting back to the compressor at 100 pounds, the idea being to utilise, as far as possible, the full pressure part of the air card. The economy is quite high, from 35 to 70 per cent., depending on the pressures carried and the character of the pump.

No. 14, compound motor pumps, refers to pumps driven by a compound air motor where heat is used before and after the high-pressure cylinder, and economies as high as 80 per cent. may be realised.

No. 15. Triple expansion, direct-acting pumps may be made to perform 300 foot-gallons of work, or 2.25 times as much as the same air will do with an ordinary direct-acting pump, by simply heating the air between the high and intermediate cylinders with the water being pumped, which has usually a 60 degree F. temperature.

No. 16 represents the air lift pump, which has an efficiency of from 25 to 60 per cent., depending upon the conditions.



AN IMPULSE WHEEL MADE BY THE PELTON WATER WHEEL CO., SAN FRANCISCO, DRIVING A CROSS COMPOUND AIR CYLINDER COMPRESSOR, BUILT BY THE RAND DRILL COMPANY

SCIENTIFIC AMERICAN SUPPLEMENT

JUNE 28, 1902.

COMPRESSED AIR LOCOMOTIVES.

THE Invalides station, which the Compagnie des Chemins de Fer de l'Ouest has just constructed, is designed principally for the service of the great lines of Brittany and Normandy, and, consequently for relieving the Saint-Lazare and Montparnasse stations. To do this, it has been necessary to establish a short line between the old junction that skirts the Seine and the Viroflay station a little beyond that of Versailles (left bank). At this place, the trains will reach the main line, upon which they will be able to run in all directions. The short line, of which the part comprised between the Invalides and Meudon is already under exploitation, is established wholly for electric traction. It constitutes the first railway line in France of which the trains are currently actuated by electric motors, for we cannot consider the two miles of the Compagnie d'Orleans comprised between Orsay and Austerlitz stations as an exploitation properly so-called.

The electricity is furnished by a central station situated at Issy, and the current is led by a third rail that accompanies the line for its entire length and upon which bear the contact shoes of the motor cars, in order to take up the power needed. This system offers a host of advantages that we shall not enumerate here; but it presents one drawback, and that is that it causes interruptions of the conductor at the changing and crossing of tracks. Upon the main line and at the approach to the stations, this is a matter of no great importance, since the speed acquired by the train easily permits of crossing switches without sensible retardation. But this is not the case in the switching about and making-up of trains at stations.

Now, since the company, by reason of the contract made with the city, cannot employ steam locomotives in the interior of the Invalides station, it has had to look for a style of smokeless locomotive capable of performing yard services. It is with such an object in view that it has recently had constructed three compressed-air locomotives which theoretically fulfill all the conditions desired. These locomotives are designed likewise for aiding trains that happen to be momentarily in distress upon the line as a consequence of the interruption of the electric current. They have been constructed in such a way that they can make the round trip between the Invalides and Versailles stations without recharging. Compressed air, employed as a motive power, especially for street car propulsion, has not given very good results; so that, upon certain lines, it has become necessary to discard it; notwithstanding the existing installations, the efficiency was deplorable. With the locomotives of the Compagnie de l'Ouest, the conditions are no longer the same, since the engines are not intended for use on the line. They have to make long trips only exceptionally, and are of interest merely for yard service at stations. The foregoing remarks as to the inconveniences found in regular service are, therefore, not applicable to them.

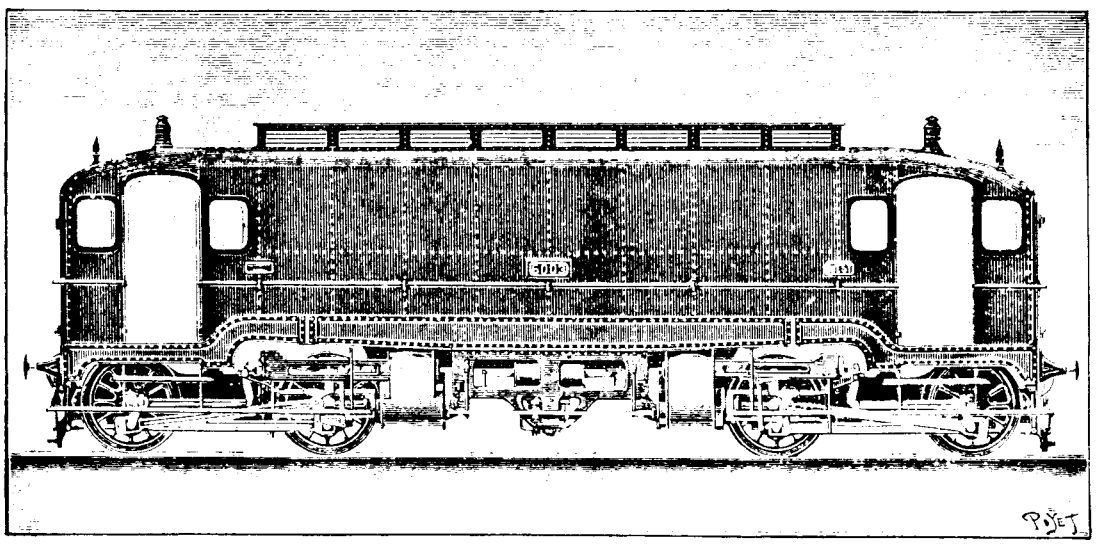
The compressed air necessary for these locomotives is produced by a small plant installed below the Esplanade des Invalides, at the level of the subterranean tracks of the new station. This plant consists of three independent groups each formed of a synchronous triphase current electric motor, which receives a 5,000-volt current from the central station at Issy, and of a Mekarski vertical air compressor of 200 horse power, making 100 revolutions a minute, and raising to a pressure of 1,422 pounds to the square inch the air that the Compagnie de l'Ouest purchases from the Compagnie Parisienne d'Air Comprimé at a pressure of 85 pounds to the square inch. Each compressor consists of four cylinders mounted in pairs in tandem, so that the same connecting rod serves for actuating the two pistons of the same group. The two cylinders of each of these two groups do not have the same duty to perform. The upper one effects the compression of the air only in the portion situated above the piston, while the lower one acts only for that of the part comprised beneath its piston. From the viewpoint of work, then, the two cylinders of a tandem may be considered as one and the same cylinder. Let us see how the compression is effected: The lower cylinder draws in the air at 85 pounds to the square inch and compresses it to an intermediate pressure and then sends it into a reservoir, whence it is sucked by the upper cylinder in which the compression is carried to 1,422 pounds to the square inch. In order to prevent heating of the metal, the cylinders are surrounded with jackets within which circulates a current of cold water. On another hand, water is allowed to flow likewise in the interior of the cylinders, so that the air coming from the compressor is always accompanied with humidity and must be dried before it is used. The air thus compressed is stored up in an accumulator composed of six groups of 20 reservoirs. The locomotives, according to their requirements, come to these latter to obtain their supply of pneumatic power. The adoption of a system of compressed air accumulators such as those above described was indispensable, since, as we have seen, the plant is supplied by the electromotive power of the line, and, as the locomotives are partly designed for the relief of the electric trains in cases of an arrest of current, it follows that the plant could not operate in cases of distress and would be unable to render the services for which it was installed if it were desired to employ recently compressed air.

Each of these three groups of compressors is capable of giving 4,400 pounds of air under pressure. Let us add that the plant is arranged in such a way that it can furnish special portable boilers designed for reheating the compressed air upon the locomotives.

These locomotives are carried by two two-axled bogies. They have the form of a baggage car, provided with two cabs, one at each end, for the engineer. This arrangement does away with the necessity of turning the engine around for running in the opposite direction. The entire mechanism, which is extremely simple, is situated under the body of the engine so that it can be easily inspected, cleaned and repaired when need be.

The main part of the locomotive contains 33 reservoirs of compressed air, which the engineer can connect with the cylinders of the motors from either cab. The motors are two in number, and situated near each of the cabs. The air passes into an intermediate reservoir before entering the motors, each of which is provided with two cylinders placed outside of the frame of the car. The first is a high pressure one of 284 pounds to the square inch, and the second a low pressure one of 143 pounds. At its two extremities, the engine is provided with special arrangements for the charging of the compressed air. It carries likewise portable steam boilers for the heating of the air.

The engineer's cabs are provided with all the apparatus necessary for operating and controlling the different parts.—For the above details and the cut we are indebted to La Nature.



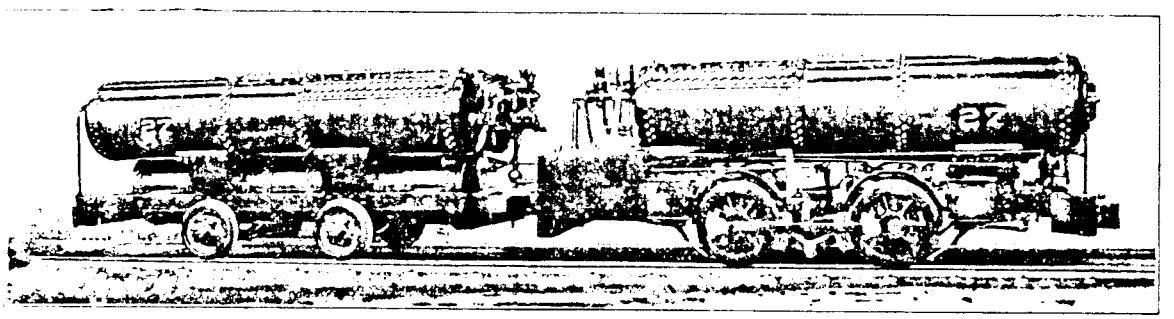
A COMPRESSED AIR LOCOMOTIVE OF THE COMPAGNIE DES CHEMINS DE FER DE L'OUEST.

COMPRESSED AIR AS A TRANSPORTATION AGENT.

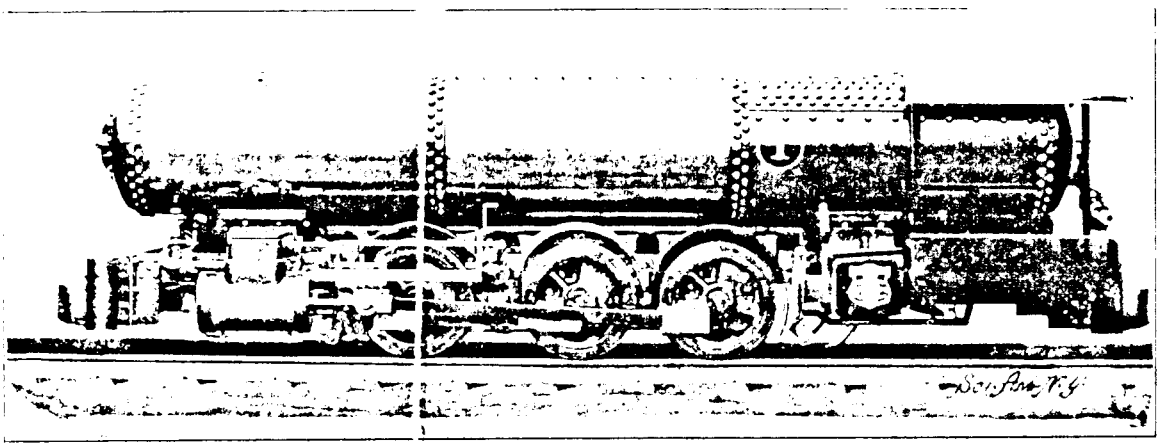
BY WALDON FAWCETT.

With a more extensive use of compressed air for power purposes has come a corresponding broadening of the scope of its employment as a transportation agent, and indeed it has been conclusively proven that pneumatic traction has decided advantages over all other forms of mechanical haulage for a large variety of operations. Prominent among these are the various phases of underground haulage. For coal mines where there is danger from mine gas its utilization is almost essential, whereas the advantages which commend its employment in non-gaseous mines are almost as potent. A rather unique field has been opened by the introduction of compressed air locomotives in railway tunnels, where the smoke, vapor and gas from steam locomotives are objectionable.

For the ordinary compressed-air haulage plant there are five essential features, namely, the locomotives, constructed to carry stored-up energy in the shape of compressed air, a charging station, a stationary reservoir, usually consisting of one or more storage tanks in which the air is compressed, an air compressor capable of compressing any desired number of cubic feet per minute to any pressure desired, and power for operating the compressor, either steam or water power being applicable for this purpose. The compressed air locomotives now most generally used are made by the H. K. Porter Company, of Pittsburg, Pa.



Pneumatic Locomotive.

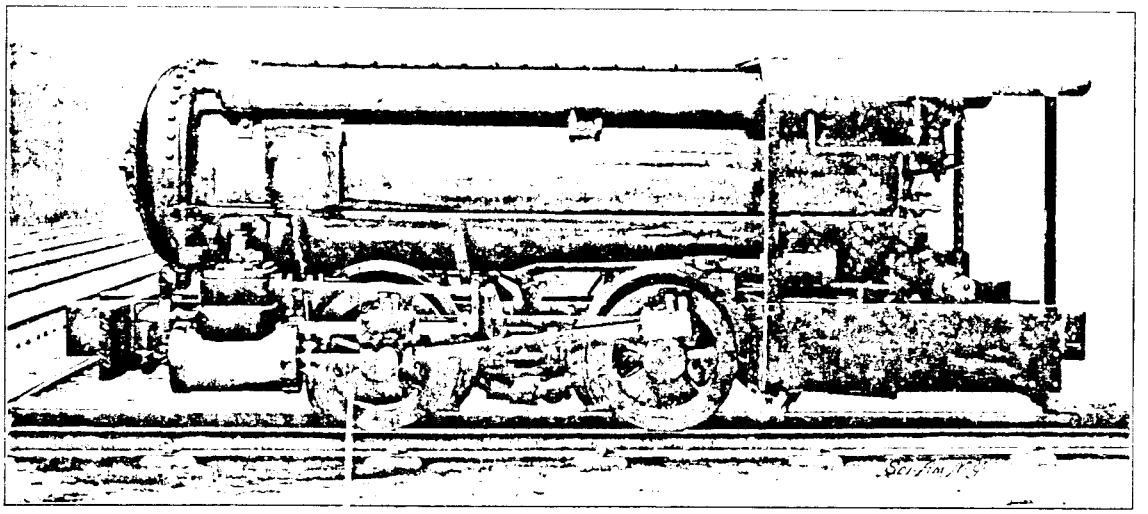


Locomotive Driven by Compressed Air.

The general machinery of an air locomotive, cylinders, frames, wheels, etc., is usually very similar to that of a steam locomotive, save that the weight is greater, the bearings larger and the details of construction stronger than in a steam machine of the same power. The main points of difference are found in the fact that instead of the usual boiler with its fuel and water accessories for developing power, the air locomotive is equipped with one or more strongly constructed main storage tanks, which are charged with compressed air at high pressure, a combination regulator and automatic stop-valve and an auxiliary low-pressure reservoir in which the air is carried at a uniform working pressure for distribution to the cylinders. The cubic capacity and the pressure of air in the main storage tanks on a motor are determined, of course, by the amount of stored energy required by the length of the run which such a locomotive is to make and the weight of the train which it is called upon to draw. Not infrequently locomotives are built to carry an air pressure of 800 or 1,000 pounds, but relief valves make it impossible to charge the motor tanks to a higher pressure than is required. The initial storage pressure decreases, of course, while the locomotive is working. As illustrating the capabilities of the compressed air motors, it may be mentioned that there are in service in this country a few locomotives which are fitted with seamless steel tubes and carry a pressure of from 1,500 to 2,500 pounds per square inch.

The combination regulator and automatic stop-valve through which the high-pressure air passes from the main storage tank to the low-pressure or auxiliary reservoir is provided with mechanism which can be instantly adjusted for maintaining whatever pressure is found most economical in the operation of the motor. Ordinarily 140 pounds per square inch is satisfactory, but in case of an emergency, such as getting derailed cars on the track, the pressure may be increased by immediate adjustment to 150 or 160 pounds. Not only is the regulation of air between the high-pressure and low-pressure reservoirs automatic, but it is at all times uniform, the air being admitted as rapidly as it is needed and at the required pressure.

For charging the locomotive storage tanks previously referred to, there are provided the charging stations, which are connected with the stationary receiver or reservoir by a pipe. It is custom-



A Compressed Air Locomotive.

ary, when the reservoir or storage system is a pipe line, to have a charging station at each end of the line, so that the motor may take a charge of air at the end of each single trip or each round trip as required. Air locomotives may be charged either direct or by a reservoir. However, direct charging is very wasteful, and consequently the method most generally accepted involves the use of the stationary reservoir.

The reservoir for a compressed-air transportation line usually consists of either a pipe line or one or more storage tanks of construction similar to the locomotive storage tank, although usually designed to carry a somewhat higher pressure. By means of the reservoir system the compressor may be kept in nearly continuous operation at a fairly uniform speed. By an automatic system of governing the compressor, when the work is light, slows down in speed, whereas when the demand for air increases, the speed is quickly brought up to the required capacity.

In a pneumatic street car the storage reservoirs are carried on the car trucks and occupy the space under the seats. The operating, brake and controller stands on the platform are very similar to the corresponding stands on an electric car. In the operation of the car, the air leaving the storage tank on the car passes through a reduction valve, where the pressure is reduced from 2,000 pounds to a working pressure of 150 pounds. It then passes into and through the water in the heater, where it takes up the moisture and heat of which it was robbed after compression and before the air was permitted to enter the station storage tanks. This is the principle that was employed on the cars experimented with on the Metropolitan system, New York. In ordinary service an air car weighing somewhat less than 10 tons will consume 400 cubic feet of free air per car mile, and in some classes of service the consumption is double that.

COMPRESSED AIR AS A TRANSPORTATION AGENT.

SRJ 1902 vol. xviii no. 1

EN 1-30-02

STREET RAILWAY JOURNAL.

NEWS OF THE WEEK

Compressed Air Cars in Brooklyn

The Brooklyn Rapid Transit Company is soon to start the operation of a compressed-air locomotive on its elevated lines. The recent fires and unavoidable accidents which have occurred in the company's power stations have reduced the available current supply to a dangerously low amount, and, notwithstanding the installation of several new rotary converters taking power from the Kings County Electric Light & Power Company, many of the old steam locomotives have been put back on the elevated. Even with these auxiliaries the slightest accident to a generator is liable to seriously cripple the service. The great advantage of a system where the cars operate independently of one another is especially marked under the Brooklyn conditions, and the adoption of compressed air may prove a satisfactory relief to the overburdened power stations. The locomotive is to be supplied by the Compressed Air Company, of New York.

COST OF COMPRESSED AIR HAULING IN A MINE.

In a paper on the subject "Compressed Air Haulage Plants," read before the Engineers' Society of Western Pennsylvania on Nov. 19, 1901, Mr. Richard Hirsch gave some data on the cost of hauling by compressed air locomotives in a Pennsylvania mine, which are of interest. The mine is Colliery No. 6, of the Susquehanna Coal Co., at Lyon, Pa. The hauling was formerly done by mules, of which over thirty were in use; the present motive power equipment consists of two compressed air locomotives, cylinders 7 × 14 ins., tank capacity 130 cu. ft., tank pressure 500 lbs. per sq. in., built by the H. K. Porter Co., of Pittsburg, Pa. The weight of each locomotive is 16,000 lbs. During the year 1897, the plant was operated a total of 179 days. The cost of operating for the year 1897, and the corresponding cost of the old style of mule-hauling, is summarized thus:

Total cost of plant, except steam boilers, cars and track	$15,156.00
Operating expenses, including all labor, fuel, supplies, repairs, etc.	2,202.78
Fixed charges, including interest, depreciation and renewals.	1,776.60
Cost of mules required for same work	4,052.48
Cost of operation by mules, including labor, supplies, interest, depreciation, etc., for 179 days.	11,328.63
Cost of operation by compressed air	3,979.38
Saving by use of compressed air	$7,349.25

At this rate of saving, the entire cost of the compressed air plant would be saved in 361 working days.

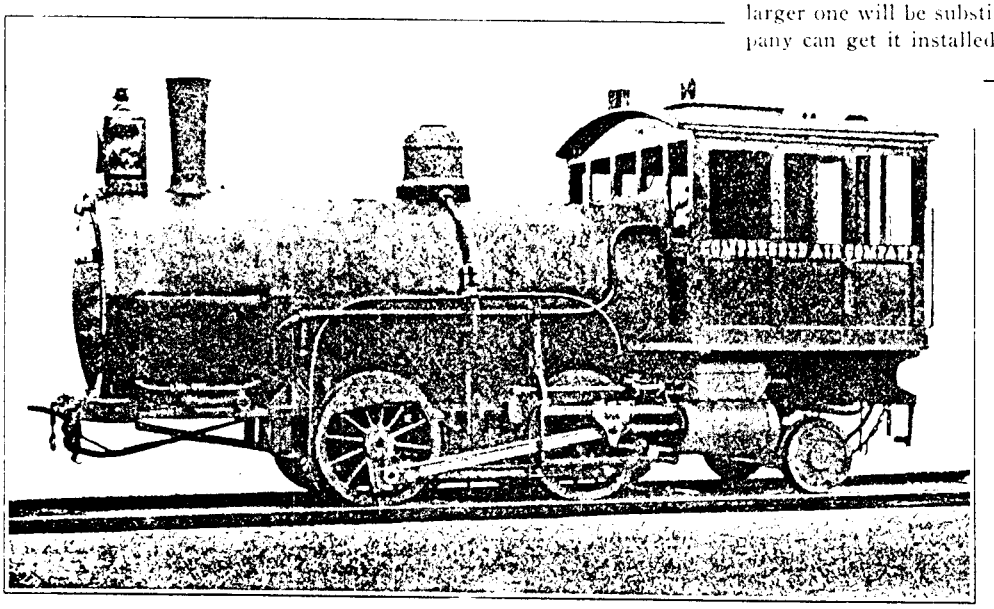
The average daily work of these two motors during the period of 179 days referred to was 1,185 net ton-miles, or the cost of hauling was 1.9 cts. per net ton-mile. The corresponding cost of hauling by mules would be 5.34 cts. per net ton-mile. Had the compressed air plant been operated for 300 days in the year, instead of 179 days, at the same daily rate of work, the cost per ton-mile would have been considerably less than that given above.

SRJ 1902 vol. xviii no. 14

Compressed Air Locomotive in Brooklyn

The accompanying illustration shows a compressed air locomotive which has been placed in operation on the Brooklyn elevated lines. The Brooklyn Rapid Transit Company was compelled some six months ago, on account of its lack of current supply, to withdraw the electrically-operated trains from the elevated service, and since that time the old steam locomotives have been in use. The company has recently, however, made arrangements with the Compressed Air Company of New York City to use one of this company's locomotives, and if the experiment proves successful more will be put in operation.

The locomotive shown in the engraving is the same one upon which such successful tests were made some months ago in Rome, N. Y., but it has been remodeled to conform to the conditions required in elevated service. As at first made, the weight upon the drivers was heavier than the specifications insisted upon by the Brooklyn company allowed, and certain modifications in the construction have therefore been adopted in order to fit it more perfectly for its new work. It has also been supplied with a headlight and dummy stack, which gives it the general appearance of the conventional steam locomotive. A compressed air plant has been installed at the end of the line near Fulton Ferry, and the compressed air locomotive has been used for drawing four-car trains on the Fulton Street line. It was found, however, that the capacity of the plant was too small to properly charge the locomotive's air tank, so that the compressor has been removed, and a larger one will be substituted as soon as the Compressed Air Company can get it installed.



COMPRESSED AIR LOCOMOTIVE FOR ELEVATED SERVICE

INCREASING THE EFFICIENCY OF COMPRESSED AIR AT THE BISBEE WEST MINE.

It is possible to prove theoretically that if the exhaust air from an air driven pump, or drill, be carried back to the compressor and used over again, there results a very great increase in the efficiency of the plant. In a recent issue of the "American Machinist," Mr. Frank Richards gives some data of an actual test secured from Mr. F. H. Wheelan, President Pneumatic Power Co., 224 California St., San Francisco. The data follow:

I am enabled to present here some data from an installation of this system at the Bisbee West Mine, near Bisbee, Arizona. The plant consists of the following: One Ingersoll-Sergeant Straight-Line air compressor, steam cylinder 16 ins. diameter, air cylinder 12¼ ins., stroke 18 ins.; one Cameron station pump, air cylinder 16¼ ins. diameter, plunger 6½ ins. diameter, stroke 18 ins. A 6 × 6 × 6-in. auxiliary air compressor is connected to the low-pressure pipe line to supply leakage in pipe line, thus keeping the pressure constant at any desired point. The duration of the test here recorded was 70 minutes.

Average Temperatures.

	Degrees F.
Inlet to compressor	69½
Receiver	162
Inlet to pump	88.8
Discharge from pump	51.6
Station	72
Engine-room	93

Gage Pressures.

	Pounds.
Inlet to compressor	83
Discharge from compressor	158.3
Inlet to pump	152.6
Discharge from pump	90.9

Mean Effective Pressures in Cylinders.

	Pounds.
Compressor	65.6
Pump	61.7

Speed.

	R. P. M.
Compressor	56.35
Pump	19.9
Auxiliary compressor	98.7

Work.

Total indicated foot-pounds in air cylinder of compressor per minute	1,208,400
Total indicated foot-pounds in air cylinder of pump, per minute	751,500

The power thus indicated at the pump is 59% of that of the compressor cylinder, while with the usual compressed air practice in driving a steam pump in this way it is rarely that more than 25% is realized.

This plant is criticised for its deficiencies by the operator of another dense air plant, where a rock drill is operated instead of a pump. The drill is 1,800 ft. from the compressor, and there are two lines of 2-in. pipe 1,300 ft. long and two lines of 1½-in. pipe 500 ft. long. The working pressure is from 215 to 220 lbs., and the return pressure 95 to 100 lbs. Notwithstanding that it is much more difficult to keep the piping around a drill tight than it is around a pump, the auxiliary compressor to make up the leakage is not run more than a quarter of the time. The compressor in this case, with air cylinder 5 ins. diameter by 9 ins. stroke, runs 90 to 95 turns per min., and besides driving the 2¾-in. rock drill in "the hardest rock I have ever seen" it also runs a 5 × 6-in. slide valve engine eight hours a day to drive a blower, and pumps 8,000 gallons of water 200 ft. high. The joints of the pipes in this case were made with shellac, which the engineer claims accounts for the small leakage. He also suggests that the pipes at the Bisbee West Mine are too small, being 2½ and 3 ins. instead of 3 and 4 ins., the latter of each of course being for the exhaust.

EN 6-18-03

COMPRESSED-AIR MOTORS FOR GATHERING CARS IN COAL MINES.*

By Beverley S. Randolph,† M. Am. Inst. M. E.

While the coal-mining practice, in regard to hauling on main roads, has advanced very rapidly in recent years by means of compressed air, electricity and ropes, that of gathering from rooms or working places has remained almost stationary. Few large mines are without some method of mechanical haulage on main roads, but the gathering from working places is still done almost entirely by means of animals or men.

An effort to improve this has been made recently by the Consolidated Coal Co., under the direction of the writer, at its mines in the Georges Creek region. The seam worked is the Pittsburg Bed, known locally as the "Big Vein." It is from 8 to 12 ft. thick. Immediately overlying the coal there is from 5 to 6 ft. of "rashings," consisting of thin alternating beds of shale and coal, which disintegrate rapidly on exposure to the air, and makes a very treacherous roof.

Rooms are driven 12 to 15 ft. wide, with a single track close to one side. A line of posts is placed just far enough from this side to leave a clear space for the mine car with a driver at the brake. This brings the post not far from the middle of the cross bar, and provides more effectual support than if placed at the end. The tracks in these rooms are usually of 4 × 4-in. oak scantling, though of late years, owing to the advance in the price of lumber and the reduction in steel rails, more of the latter are being used. This track is laid by the miner. His pay for the work is included in the price per ton for mining. It is therefore, as a rule, unskillfully and often carelessly laid, and cannot be relied upon to carry safely any weight materially greater than the loaded mine car.

Compressed air was already in use on the main roads, driving motors weighing 30,000 lbs. each, which are used to haul the mine cars that have been assembled from the rooms, bringing them to the foot of a slope, from where they are hauled to daylight by means of a rope.

At the suggestion of the writer, the Baldwin Locomotive Works designed a motor, having the dimensions and general character shown in the accompanying cut, and guaranteed not to weigh more than 8,000 lbs. when charged. Loaded mine cars frequently weigh 7,000 lbs. gross, and their outside dimensions are then practically the same as the motor just mentioned.

Five of these machines were placed in the company's Ocean No. 3 mine (Hoffman), displacing a number of mules, but leaving 19 still working. This opportunity was embraced to make a close comparison between the two methods of gathering.

COST OF MULE HAULAGE.

The mules working in the north heading and the south heading deliver their cars directly to the rope on the slope. The other mule routes deliver to the heavy motors mentioned above, as do all the motor routes. The mules used weigh from 1,200 to 1,400 lbs., and are the best obtainable. Mine cars weigh 1,600 lbs., and carry an average of 2.4 long tons.

The following table shows the work performed by the mules during a period of 18¾ working days in the month of December, 1902:

Route	Cars moved.	Average haul, ft.	Constant. 2·4 / 1000	Tons moved 1,000 ft.
South heading	1,119	2,900	"	7,788.24
North heading	268	1,300	"	836.16
First cross	1,629	2,100	"	8,210.16
Second "	3,042	1,110	"	8,030.88
Third "	747	400	"	717.12
Total				25,582.56

This represents a total of 339 days' work for one mule.

The company's accounts show a cost of $1.15 per day for each day worked by a mule, including expense of replacing worn-out animals. Drivers are paid $1.98, and there is one with each mule. This makes a cost of $3.13 per day for each day worked by a mule. The cost per ton hauled 1,000 ft. would therefore be

$$\frac{339 \times \$3.13}{25{,}582.46} = 4.15 \text{ cts.}$$

COST OF MOTOR HAULAGE.—For the work of the motors during the same time we have:

Route	Cars moved.	Average haul, ft.	Constant. 2·4 / 1000	Tons moved 1,000 ft.
Tippens	1,122	2,300	"	6,193.44
Scobles	1,073	2,050	"	5,279.16
First Klondyke	1,147	1,835	"	5,046.80
Second "	1,032	1,800	"	4,458.24
Third "	1,147	1,865	"	5,138.56
Fourth "	114	1,992	"	544.92
Total				26,661.12

This work was done by the five small motors operated by compressed air, working a total of 94 days.

This plant is supplied with steam by a battery of boilers, which also supplies steam to the large pumps. The plant consists of the following items, with their approximate first cost:

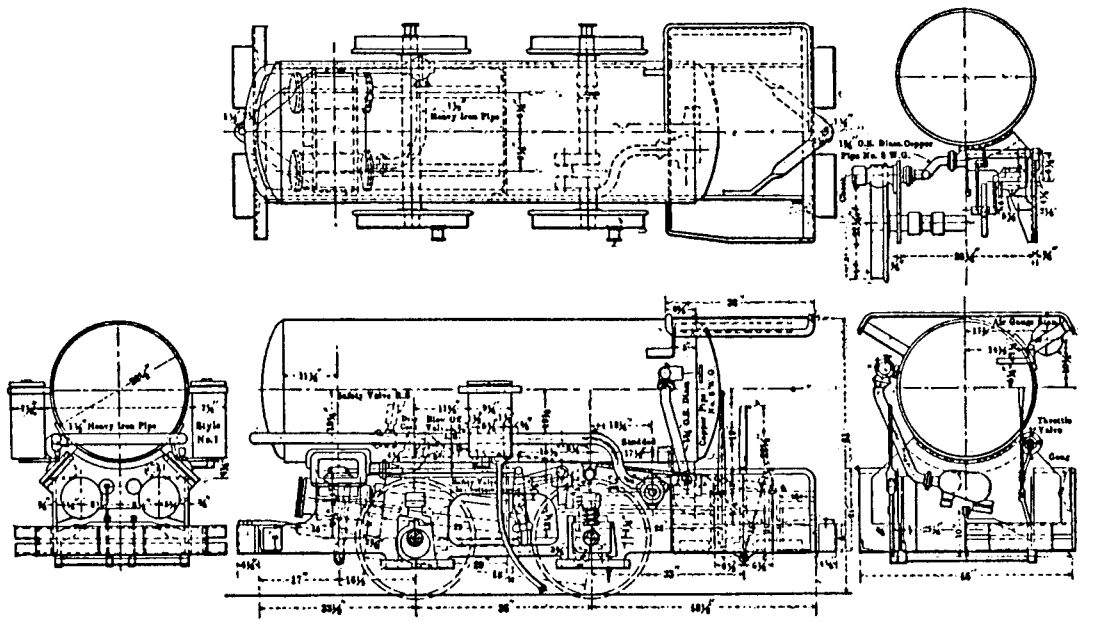
One straight line Norwalk air compressor, 18 and 28 compound steam, 18½, 13½ and 6½ three-stage air, 30-in. stroke	$5,300
5,600 ft. 5-in. pipe	6,600
3,100 " 2½-in. pipe	1,700
1,000 " 1½-in. pipe	300
2 motors, 30,000 lbs. each	6,000
5 motors, 8,000 lbs. each	10,000
Estimated proportion of boilers	1,000
Installation	4,000
Total	$33,900

Allowing $3,000 per year for interest and depreciation, to be earned in 300 working days, would justify a charge of $10 per day from this source against the entire plant.

This same compressor also drives the large motors mentioned above, which weigh 30,000 lbs. each (60,000 lbs. for the two); the five small machines weigh 8,000 lbs. each (40,000 lbs. for the five). Dividing the general expenses according to the weight would result in four-tenths being charged against the small motors.

*A paper read at the Albany meeting of the American Institute of Mining Engineers.

†Mine Supt., Cons. Coal Co., Frostburg, Md.



COMPRESSED AIR LOCOMOTIVE USED BY CONSOLIDATION COAL CO., FROSTBURG, MD.

These general expenses may be summed up as follows per day:

Coal, 4 tons at $1	$4.00
Firemen	2.00
Mechanic in charge of compressor	2.50
Interest and depreciation	10.00
Total	$18.50

The daily cost of operation of the five small motors would then be

5 motormen at $2.67	$13.35
5 brakemen at $2.03	10.15
General expenses, $18.50 × 0.4	7.40
Repairs and oil	3.00
Total	$33.78

Dividing this among the five machines would give $6.78 per day for each machine, and the cost per ton moved 1,000 ft. would be

$$\frac{6.78 \times 94}{26,661.12} = 2.44 \text{ cts.}$$

In the matter of continuity of service, the motors show to great advantage. A broken-down motor can usually be repaired over night, while an injured mule can only be replaced by a new one that must usually be broken and inured to the work before he is thoroughly efficient, entailing loss of time and output in each case.

In the actual placing of cars in the workings, the motor has little or no advantage over the mule. After the train is made up, its higher speed and larger load place the mule at a great disadvantage. The showing of the motors may, therefore, be expected to be better with long hauls than with short.

Owing to the fact that it is the practice in this mine to send the same motor or mule on different routes, depending on where miners may be loading coal, it is impracticable to present any discussion of this feature from the data at hand.

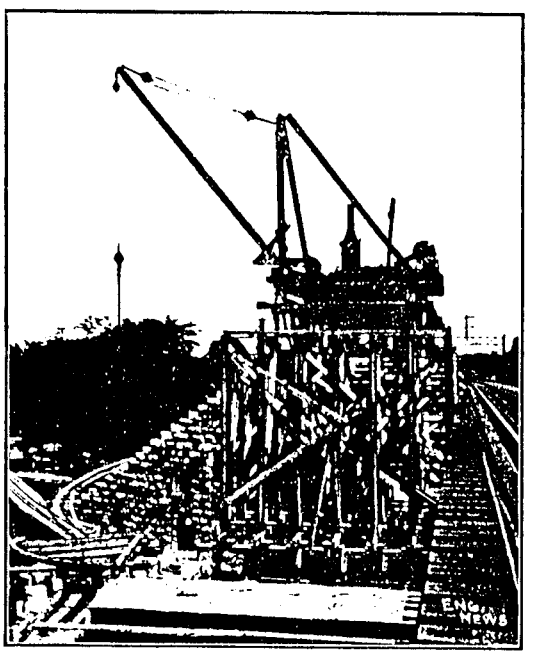


Fig. 4. View Showing Traveling Derrick Erecting Center for Raritan River Bridge.

Transactions of the American Institute of Mining Engineers 1903

Compressed-Air Motors for Gathering Cars in Coal-Mines.

BY BEVERLEY S. RANDOLPH, FROSTBURG, MD.

(Albany Meeting, February, 1903.)

WHILE our coal-mining practice, in regard to hauling on main roads, has advanced very rapidly in recent years by means of compressed air, electricity and ropes, that of gathering from rooms or working-places has remained almost stationary. Few large mines are without some method of mechanical haulage on main roads, but the gathering from working-places is still done almost entirely by means of animals or men.

An effort to improve this has been made recently by the Consolidation Coal Company, under the direction of the writer, at its mines in the Georges Creek region. The seam worked is the Pittsburg bed, known locally as the "Big Vein." It is from 8 to 12 feet thick. Immediately overlying the coal there is from 5 to 6 feet of "rashings," consisting of thin alternating beds of shale and coal, which disintegrate rapidly on exposure to the air, and making a very treacherous roof.

Rooms are driven from 12 to 15 ft. wide, with a single track close to one side. A line of posts is placed just far enough from this side to leave a clear space for the mine-car with a driver at the brake. This brings the post not far from the middle of the cross-bar, and provides more effectual support than if placed at the end. The tracks in these rooms are usually of 4 in. x 4 in. oak scantling, though of late years, owing to the advance in the price of lumber and the reduction in steel rails, more of the latter are being used. This track is laid by the miner. His pay for the work is included in the price per ton for mining. It is therefore, as a rule, unskillfully and often carelessly laid, and cannot be relied upon to carry safely any weight materially greater than the loaded mine-car.

Compressed air was already in use on the main roads, driving motors weighing 30,000 pounds each, which were used to bring the mine-cars that had been assembled from the rooms to the slopes, through which they were hauled to daylight by means of ropes.

At the suggestion of the writer, the Baldwin Locomotive Works designed a motor, having the dimensions and general character shown in accompanying drawing (Fig. 1), and guaranteed not to weigh more than 8000 pounds when charged. Loaded mine-cars frequently weigh 7000 pounds gross, and their outside dimensions are then practically the same as the motor just mentioned.

Five of these machines were placed in the Company's Ocean No. 3 mine (Hoffman), displacing a number of mules, but leaving 19 still working. This opportunity was embraced to make a close comparison between the two methods of gathering.

The mules working in the North Heading and the South Heading deliver their cars directly to the rope on the slope. The other mule-routes deliver to the heavy motors mentioned above, as do all the motor-routes. The mules used weigh from 1200 to 1400 pounds, and are the best obtainable. Mine-cars weigh 1600 pounds, and carry an average of 2.4 long tons.

The following table shows the work performed by the mules during a period of $18\frac{3}{4}$ working days in the month of December, 1902:

Route.	Cars Moved.	Average Haul.	Constant.	Tons Moved 1000 ft.
South heading	1119	2900 ft.	$\frac{2.4}{1.6.6.0}$	7788.24
North "	268	1300 "	"	836.16
1st Cross	1629	2100 "	"	8210.16
2d Cross	3042	1100 "	"	8030.88
3d Cross	747	400 "	"	717.12
Total				25,582.56

This represents a total of 339 days' work for one mule.

The company's accounts show a cost of $1.15 per day for each day worked by a mule, including expense of replacing worn-out animals. Drivers are paid $1.98, and there is one with each mule. This makes a cost of $3.13 per day for each day worked by a mule. The cost per ton hauled 1000 feet would therefore be

$$\frac{339 \times \$3.13}{25{,}582.56} = 4.15 \text{ cents.}$$

For the work of the motors during the same time we have:

Route.	Cars Moved.	Average Haul.	Constant.	Tons Moved 1000 ft.
Tippens....................	1122	2300 ft.	$\frac{2.4}{1000}$	6193.44
Scobies....................	1073	2050 "	"	5279.16
1st Klondyke............	1147	1835 "	"	5046.80
2d "	1032	1800 "	"	4458.24
3d "	1147	1865 "	"	5138.56
4th "	114	1992 "	"	544.92
Total..........				26,661.12

This work was done by the five small motors operated by compressed air, working a total of 94 days.

This plant is supplied with steam by a battery of boilers, which also supplies steam to the large pumps. The plant consists of the following items, with their approximate first cost:

One straight-line Norwalk air-compressor, 18 and 28 compound steam, 18½, 13½ and 6½ three-stage air, 30-in. stroke,	$5,300
5600 feet of 5-inch pipe,	5,600
3100 " 2½-inch "	1,700
1000 " 1½-inch "	300
2 motors, 30,000 lbs. each,	6,000
5 " 8,000 lbs. each,	10,000
Estimated proportion of boilers,	1,000
Installation,	4,000
	$33,900

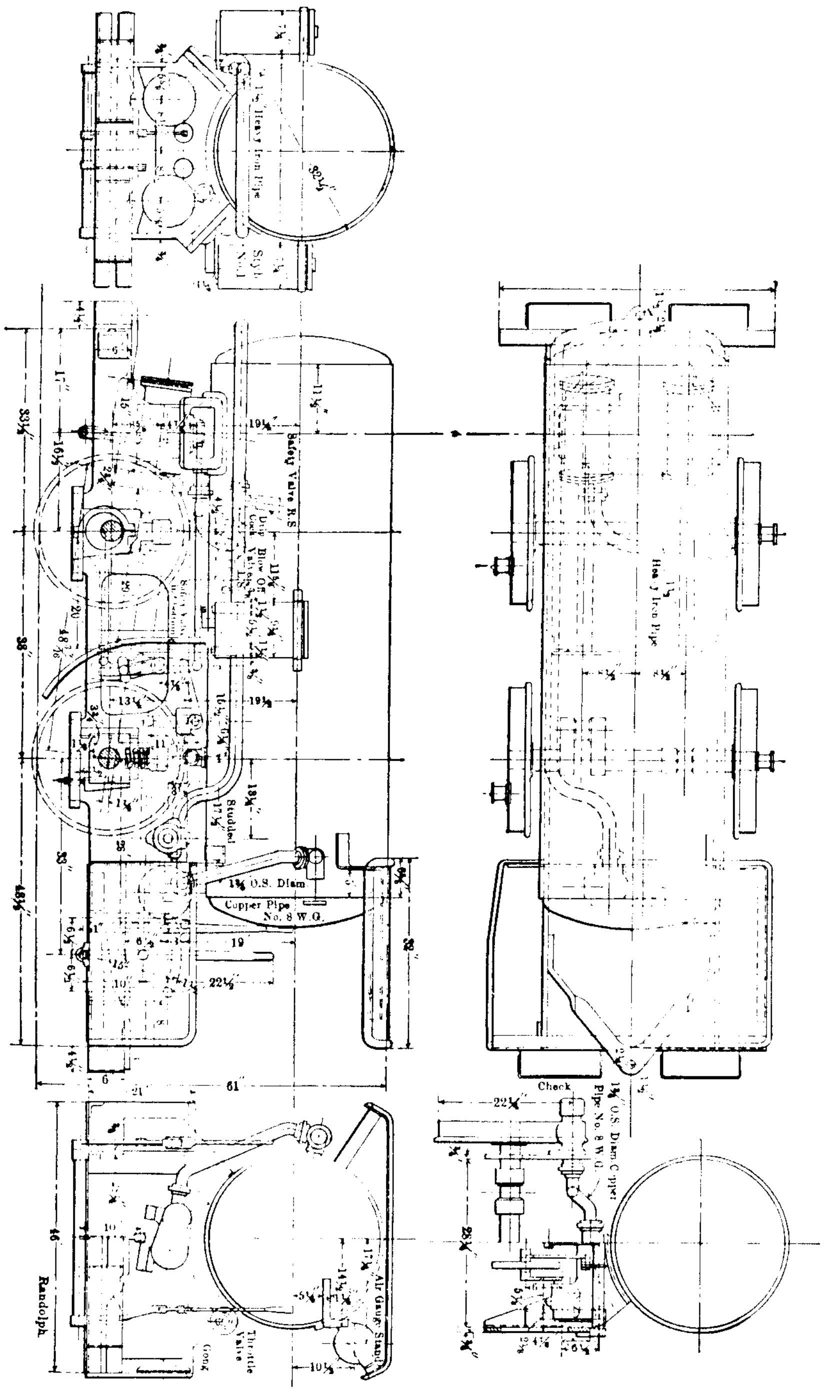
Allowing $3000 per year for interest and depreciation, to be earned in 300 working-days, would justify a charge of $10 per day from this source against the entire plant.

This same compressor also drives the large motors mentioned above, which weigh 30,000 lbs. each (60,000 lbs. for the two); the five small machines weigh 8000 lbs. each (40,000 lbs. for the five). Dividing the general expenses according to the weight would result in four-tenths being charged against the small motors.

These general expenses may be summed up as follows per day:

Coal, 4 tons @ $1,	$4.00
Fireman,	2.00
Mechanic in charge of compressor,	2.50
Interest and depreciation,	10.00
	$18.50

Fig. 1.

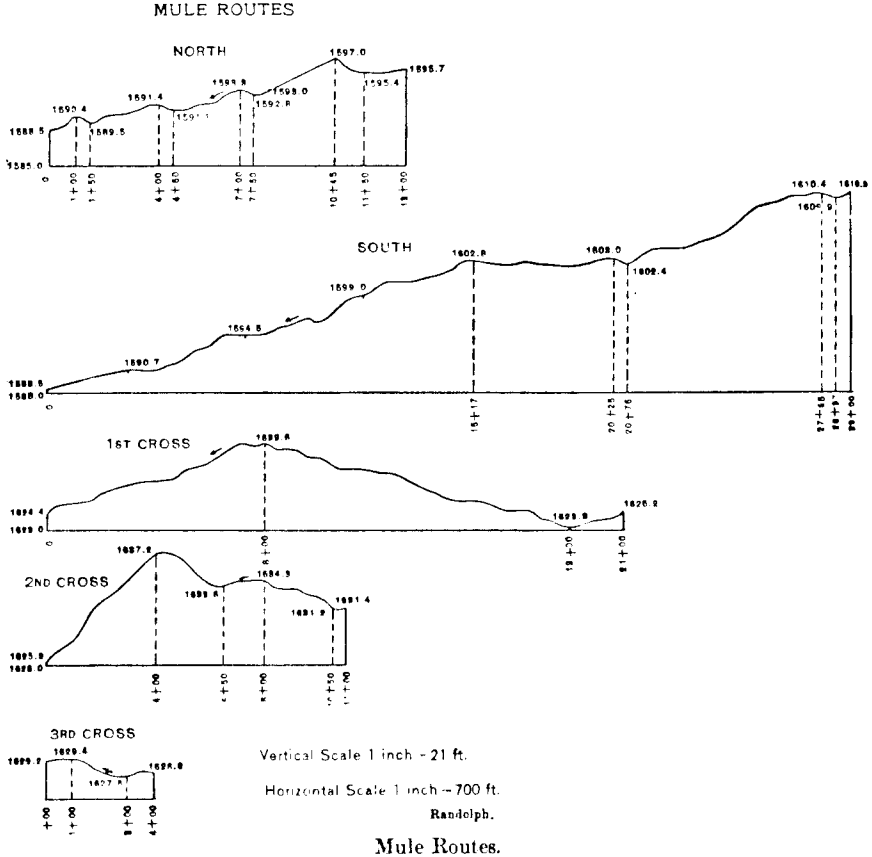


Motor Used by the Consolidation Coal Company.

The daily cost of operation of the five small motors would then be

5 Motormen at $2.67,	$13.35
5 Brakemen at $2.03,	10.15
General expenses, $18.50 x .4,	7.40
Repairs and oil,	3.00
	$33.90

FIG. 2.



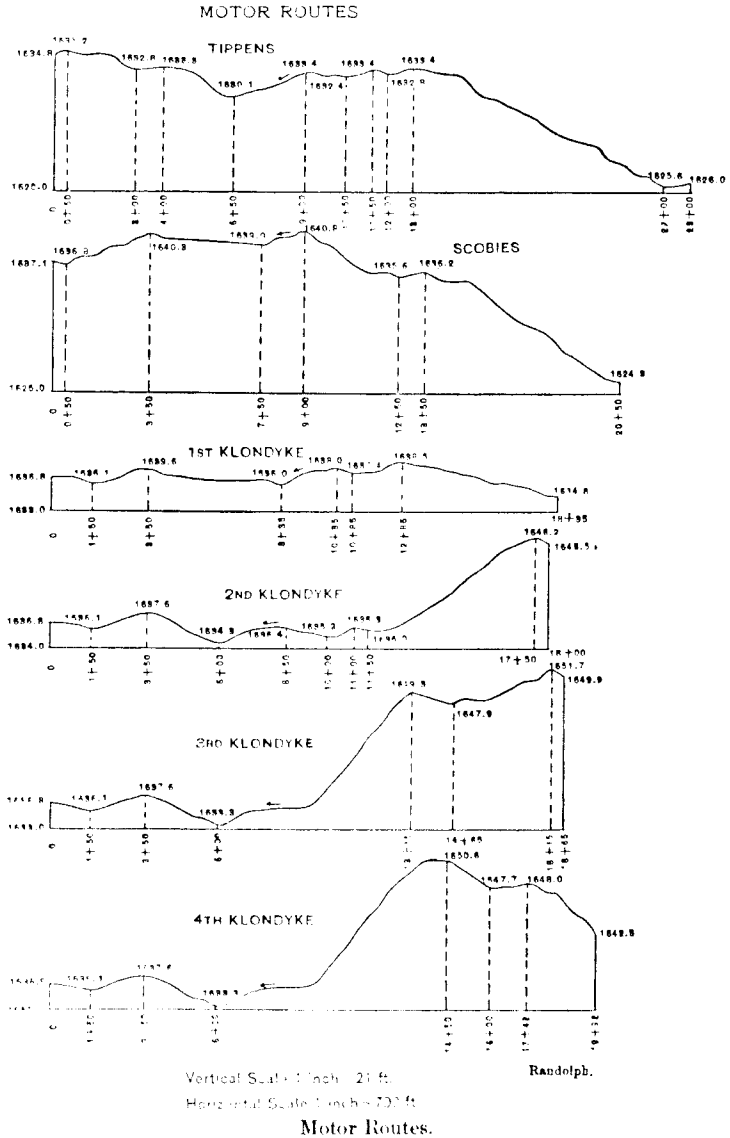
Mule Routes.

Dividing this among the five machines would give $6.78 per day for each machine, and the cost per ton moved 1000 feet would be

$$\frac{6.78 \times 94}{26{,}661.12} = 2.44 \text{ cents.}$$

In the matter of continuity of service, the motors show to great advantage. A broken-down motor can usually be repaired over night, while an injured mule can only be replaced by a new one that must usually be broken and inured to the

FIG. 3.



Motor Routes.

work before he is thoroughly efficient, entailing loss of time and output in each case.

In the actual placing of cars in the workings, the motor has

little or no advantage over the mule. After the train is made up, its higher speed and larger load place the mule at a great disadvantage.

The showing of the motors may, therefore, be expected to be better with long hauls than with short.

Owing to the fact that it is the practice in this mine to send the same motor or mule on different routes, depending on where miners may be loading coal, it is impracticable to present any discussion of this feature from the data at hand.

Figs. 2 and 3 show the profiles of the various routes. The loads move from right to left. From this it will be seen that, so far as grades are concerned, the motors are at a decided disadvantage in this comparison. The elevations refer to mean tide at Baltimore.

CASSIER'S MAGAZINE 1904 Volume 26

INDUSTRIAL LOCOMOTIVES

FOR MINING, FACTORY, AND ALLIED USES

PART II.—COMPRESSED AIR AND INTERNAL COMBUSTION LOCOMOTIVES

By J. F. Gairns

THE use of compressed air as a motive power for locomotives has received the attention of inventors for many years; indeed, in the early days of the steam locomotive, "atmospheric" railways, as they were termed, bid fair, according to inventors and financiers, to be serious rivals of the steam engine, for several railways were actually built and equipped for compressed air working in Great Britain. In no instance, however, were they practically or commercially successful, and the atmospheric system soon disappeared. Nevertheless, in view of the cleanliness and handiness of compressed air locomotives and their adaptability to certain services, inventors have persevered, and several undoubtedly satisfactory machines were introduced on the New York elevated lines, for tunnel work, for tramway purposes, and, as will be seen hereafter, for mining and like use.

In consequence, however, of developments in electric traction, the compressed air locomotive has hardly had a fair chance. It is probable that had not electricity provided a remedy for the disadvantages and inconveniences of the steam locomotive in particular circumstances, the compressed air locomotive would have an established position on local railways and tramways and for miscellaneous use. For mining and factory work the pneumatic locomotive is eminently suitable, for it can be made very compact and can be very conveniently arranged as regards construction; there is no furnace to be a possible source of danger and to cause the emission of fumes and smoke; and it can be used in an explosive atmosphere. It has even been claimed that the use of compressed air locomotives in mines assists in ventilation and in the supply of pure air to the workings.

In single units, compressed air cannot be economically installed, but when there is an air-compressing plant provided for working coal-cutting and other machinery, and there is a number of locomotives to be supplied from the same central station, compressed air traction can be very advantageously introduced. There are many collieries in the United

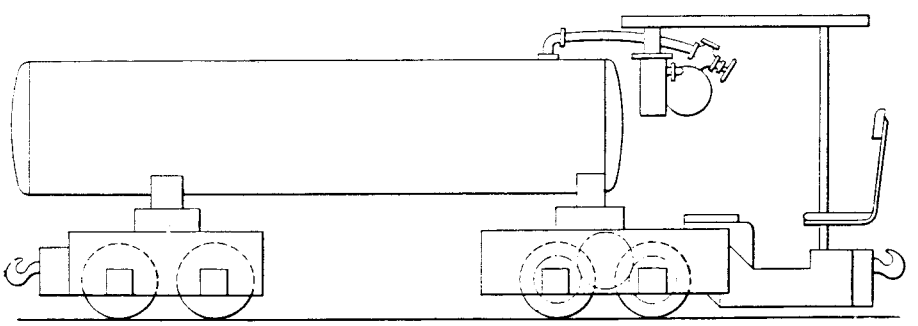


FIG. 27.—A COMPRESSED AIR MINE LOCOMOTIVE FOR A GERMAN MINE

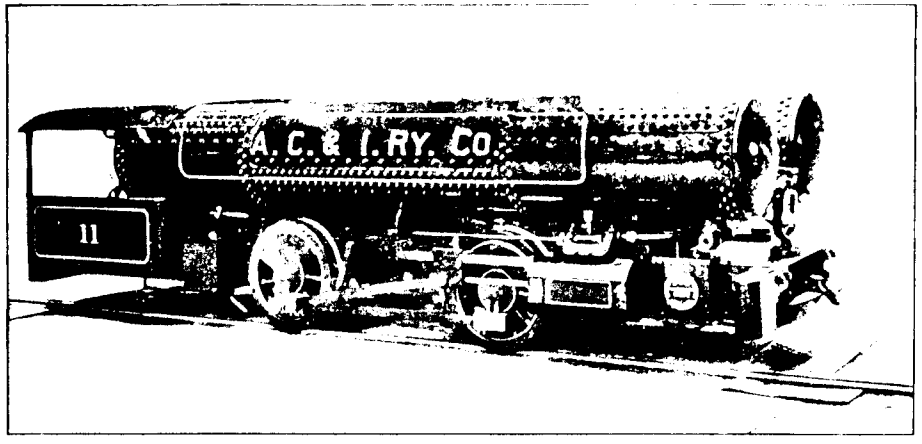


FIG. 28.—A COMPRESSED AIR MINE LOCOMOTIVE BUILT FOR THE ASHLAND COAL & IRON RAILWAY CO. BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA

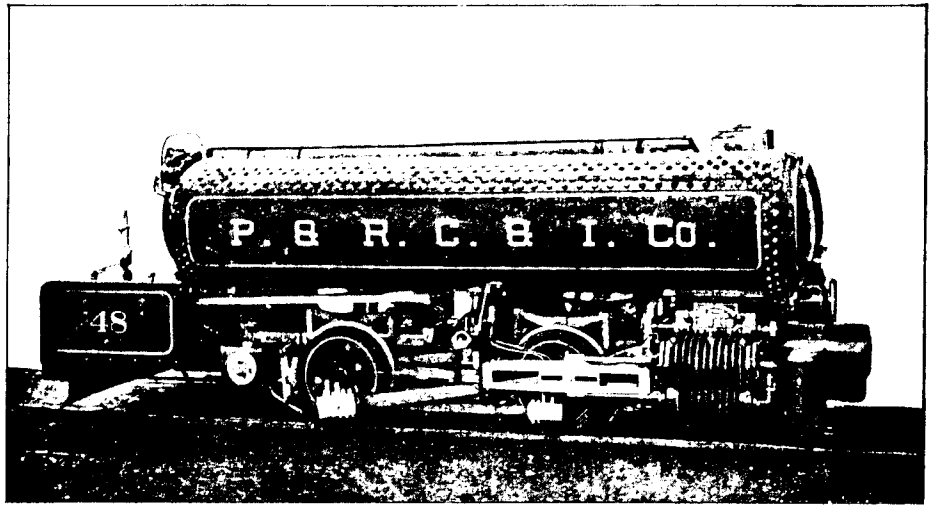


FIG. 29.—A COMPOUND COMPRESSED AIR MINE LOCOMOTIVE BUILT FOR THE PHILADELPHIA & READING COAL & IRON CO. BY THE BALDWIN LOCOMOTIVE WORKS. NOTE THE SMALL AIR TANK ON TOP OF THE TWO LARGE ONES

States and a few in other parts of the world using compressed air locomotives, though in Germany electric traction is almost universal, and Great Britain possesses hardly any mines where locomotive traction is used at all. There is not much diversity in the design of such locomotives, and the building of them is principally confined to certain firms; but, as will be seen, considerable interest attaches to the designs in use.

The writer is not aware of any compressed air locomotives in use for any kind of work in Great Britain, or built by British firms, and on the continent there is a similar condition of affairs. There is one German mine, however, where the locomotive power is provided by compressed air,—pneumatic winding plants operated by underground compressed air engines supplied from compressors above ground are not uncommon, but they do not come within our subject. Fig. 27 is a side elevation of the form of locomotive in use in this instance. As it possesses many noteworthy and unusual characteristics, it will be worth while to describe it more in detail than is generally possible in this article, the particulars being taken from the "Jahrbuch für das Berg und-Hüttenwesen im Konigreich-Sachsen," for 1894.

At the mine in question,—the "Alte Hoffnung Gottes" mine, near Freiberg,—compressed air was installed for working machinery in the mine in 1883, some old boilers being used as reservoirs below ground, and in 1891 a locomotive was introduced for bringing the laden tubs to the foot of the main shaft. The longest journey made by the locomotive is about 1000 metres; but the route is very irregular, and there are several almost right angular turns. The locomotive is mounted on two pivoted, four-wheeled bogie trucks, to provide for the requisite flexibility, the bogies being spaced 2.3 metres between centres. The main reservoir is 3.16 metres long and 0.7 metres in diameter, and air is supplied to it at a pressure of 12 or 18 atmospheres, the former pressure being used for the journey with empty tubs and the latter on the loaded trip. For use, the air passes to a small reservoir, and thence, past a reducing valve, to a double-cylinder, vertical engine, with cylinders 80 millimeters in diameter, of 200-millimetre stroke, and with a usual working speed of about 100 revolutions per minute, the air being used at a pressure of 4 or 5 atmospheres. The engine is mounted on one of the supporting bogies, and drives directly one axle, which is cranked, and drives the other axle of the same bogie indirectly by means of spur gearing arranged between the cranks.

The usual air pressure for use in the mine is only about 5 atmospheres, and for supplying the locomotive a small compressor has been fitted, which raises the pressure on either side of the compressing piston to 12 and 18 atmospheres, respectively, the air at one pressure being conveyed by pipes to the further limit of the locomotive route, and supplied at the other pressure to the locomotive adjacent to the compressor. The locomotive has limiting dimensions of height 1.6 metres (about 5 feet), and width about 1 metre. The gauge is 410 millimetres (about 16 inches). The usual load hauled by this little machine is four waggons, weighing about 14 cwt. loaded.

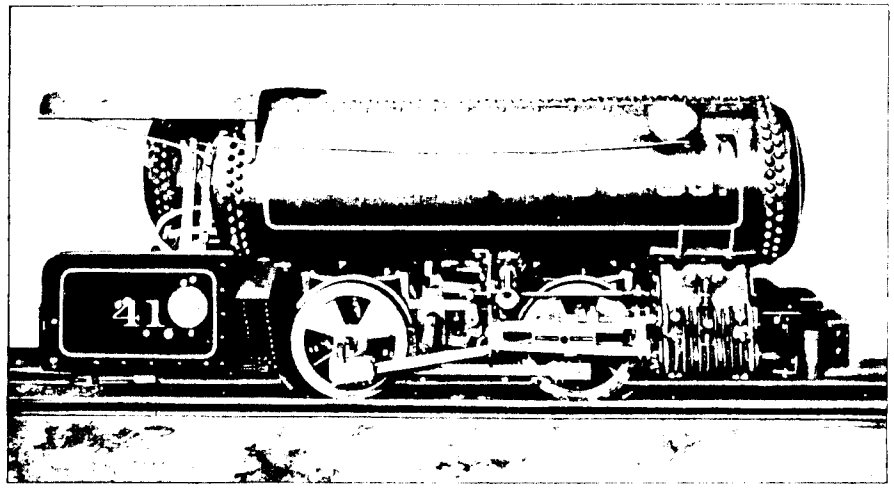


FIG. 30.—ANOTHER BALDWIN ENGINE. ONE OF THE AIR TANKS IS SHORTER THAN THE OTHER TO PROVIDE MORE ROOM IN THE CAB

In America the design and building

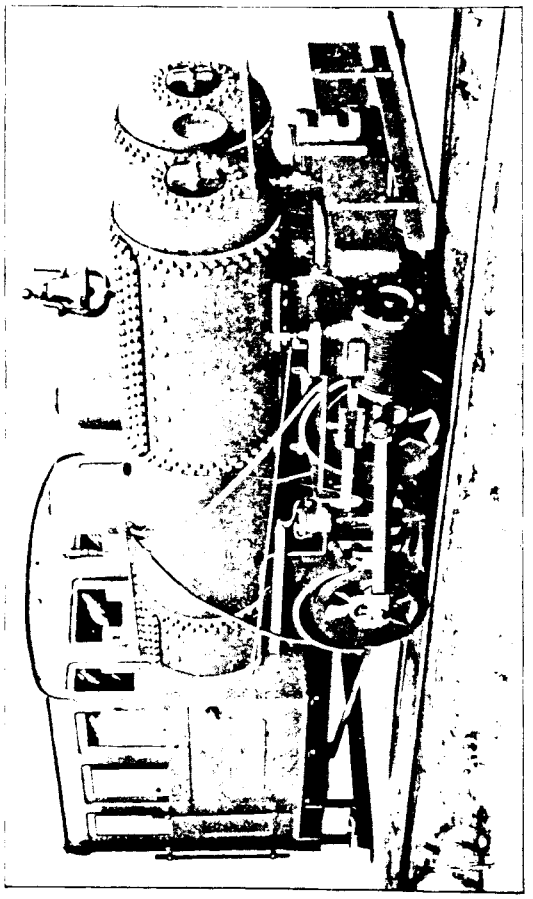


FIG. 32.—A HEAVY COMPRESSED AIR SHIFTING LOCOMOTIVE MADE BY THE H. K. PORTER COMPANY, PITTSBURGH, PA

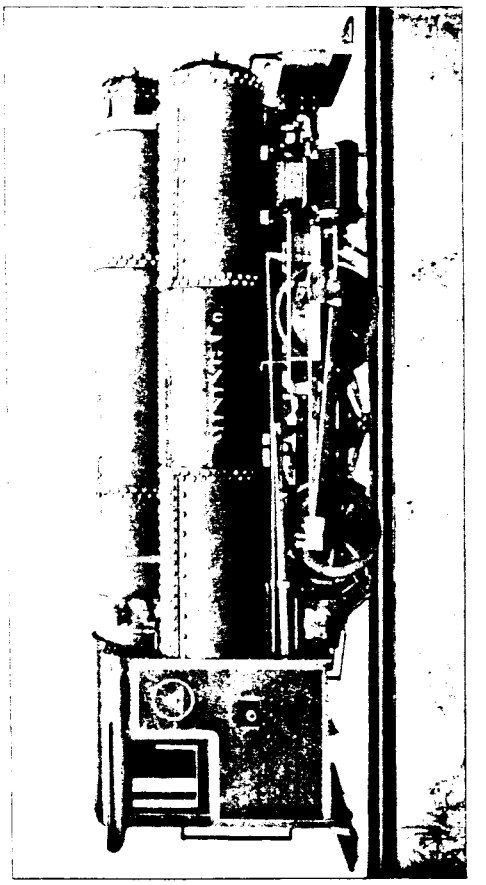


FIG. 33.—A HEAVY THREE-TANK COMPRESSED AIR LOCOMOTIVE FOR UNDERGROUND WORK IN THE MINES OF THE HOMESTAKE MINING CO. MADE BY THE H. K. PORTER COMPANY

of compressed air locomotives for mining service forms an important part of the business of the leading locomotive firms, more particularly the Baldwin Locomotive Works, of Philadelphia; the American Locomotive Company, of New York, and the H. K. Porter Company, of Pittsburgh.

The following notes from the latest "Record of Recent Construction," issued by the Baldwin Works, concerning compressed air mining locomotives, will be interesting:—

Locomotives particularly adapted to mine haulage were first used in the United States about the year 1870. These early locomotives were operated by steam, and proved vastly more efficient and economical than the prevailing system of hauling by animal power.

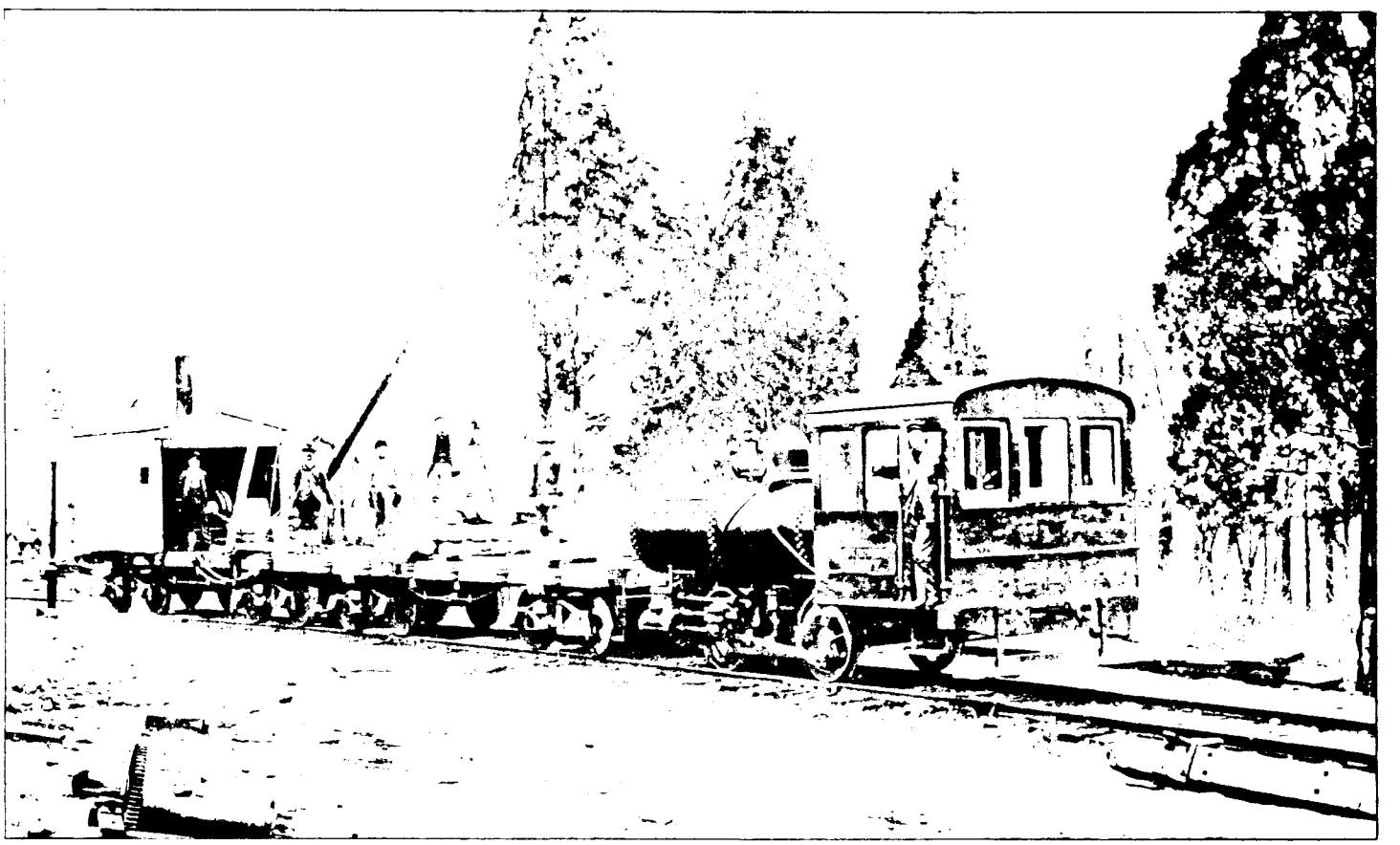


FIG. 31.—ONE OF THE H. K. PORTER COMPANY'S COMPRESSED AIR LOCOMOTIVES IN SURFACE USE FOR CONSTRUCTION WORK

Their use, however, was limited to the main gangways of well-ventilated mines on account of the danger and inconveniences from fire and escaping steam and gases. In order to overcome the difficulties attending the use of steam, compressed air was substituted. A reservoir was provided for the reception of the air, to take the place of the steam boiler, making no material change in the arrangement of the machinery. In this way the efficiency derived from the use of the locomotive was retained and danger avoided.

In the process of compression a large amount of heat is necessarily generated. This heat passes off and is lost as the temperature falls to that of the surrounding atmosphere. When the air is expanded in the locomotive a drop in temperature results, reaching far below that of the atmosphere: this has a marked effect on the final volume of the air used in the cylinders. An increase in economy and efficiency will, therefore, be obtained by restoring to the air some of its lost heat. An efficient system of reheating would be highly desirable were it not for the complication involved, and the fact that for mine service the process of reheating brings with it the very danger which the use of the compressed air locomotive is intended to avoid. It should be borne in mind, however, that the temperature of the expanding air falls far below that of the surrounding atmosphere, which, under these conditions, acts as a reheating medium by contact with the outer surfaces of the tanks and cylinders. Any increase, therefore, in the amount of surface of tanks or cylinders exposed to the atmosphere is a direct gain. In view of this fact, the outer surfaces of the cylinders are ribbed, causing them to present a greater area for absorption.

Within certain limits compressed air is preferable to steam or electricity for mine haulage. Compressed air locomotives, as compared with those using steam, differ but slightly, so far as the machinery is concerned. The steam generating apparatus is entirely eliminated, simplifying the construction and doing away with the part of the locomotive which requires the greater amount of skill to operate. As long as the air supply is maintained, they are capable of handling the same load in proportion to their tractive power as locomotives operated by steam, and have the advantage of being entirely free from fire, gas or vapour.

With electricity, especially for large units, the trolley system is the only one ordinarily available, and the locomotive is confined in its range to that of the supply conductor, whereas with compressed air the locomotive is at liberty to run in any direction on any available track to the limit of its charge. The cost of installation for compressed air compares favorably with that for electricity.

It is possible to charge the locomotive direct from the compressor, but this system, although economical in some respects, would necessitate an increase in size of both the compressor and the locomotive. It is preferable, therefore, to provide stationary reservoirs at convenient points in the mine, from which a supply of air can be readily drawn to recharge the locomotive tanks. This enables the compressor to be run continuously and restore the depleted reservoirs to their normal pressure while the locomotive is doing its work. Where the system requires a considerable length of piping, the pipe line in itself will supply sufficient capacity without extra stationary reservoirs.

The charging stations should be located at convenient points, preferably at the ends of the run, or where the locomotive is, for other reasons, required to stop. This will economise the air by avoiding the necessity of running the engine any considerable distance simply for the purpose of recharging. The connection and stop valves for the charging stations are arranged with a view to ready adjustment and speedy supply, in order that the locomotives may not be detained longer than is absolutely necessary while receiving their charge. After the operation becomes familiar, the time required for making connections and recharging is ordinarily less than one minute.

A compressed air locomotive consists essentially of a storage tank mounted upon driving wheels, with two engines to convert the pressure in the tank into direct motion at the wheels. The general details of construction and the materials respectively employed are similar throughout to those of locomotives operated by steam. One or more reservoirs or storage tanks may be employed, as may be found most suitable to meet prescribed conditions. Compound cylinders are sometimes applied to compressed air locomotives. With this system the cycle of expansion occupies a longer period of time for the same speed, and consequently a greater opportunity for heat absorption from the outside atmosphere is obtained.

One of the first compressed air locomotives to be put in successful operation was built by the Baldwin Locomotive Works for the Plymouth Cordage Company, of North Plymouth, Mass. The locomotive, one of small size, having a single tank and cylinders 5 by 10 inches, was ordered in 1876 and placed in service in April, 1877. It was used for general switching purposes and to transfer material from the storehouse to the factory, taking the place of four one-horse teams, with three men to each team.

The conditions of service under which the locomotive was required to operate were such as to preclude the use of steam. The fine particles of material with which the air was sometimes impregnated were highly combustible and no fire could be permitted, and the material under construction was liable to damage from the dampness occasioned by escaping steam. The compressed air locomotive, which was free from both fire and moisture, proved satisfactory to such a degree that another similar locomotive was ordered in 1894, and two others have since been placed in service.

As illustrative of American practice, two examples of pneumatic locomotives, built at the Baldwin Works, are shown in Figs. 28 and 29. There is no great variety among these locomotives, and so these examples will be sufficient for consideration in this article.

Fig. 28 shows a compressed air locomotive for the Ashland Coal & Iron Railway Company. There are three storage tanks, two of which are visible in the illustration, and a third, of smaller dimensions, is fitted between the frames. One of the large tanks is shorter than the other, to provide additional room in the cab. The air is stored at a pressure of 600 lbs. per square inch, and is used at 100 lbs. This engine requires a headway of 5 feet in height and 6 feet in width only. It will take curves of a 30-foot radius.

Fig. 29 illustrates a compressed air locomotive, compounded on the Vauclain system, as built for the Philadelphia & Reading Coal & Iron Company. In this engine, also, three storage tanks are provided, and the small one, from which air is taken for the cylinders, is distinctly visible in the illustration, above and between the larger reservoirs. Each low-pressure cylinder is above the high-pressure cylinder in one casing, and both are ribbed to facilitate the abstraction of heat from the atmosphere, as the air under pressure expands in doing its work The air is stored at a pressure of 600 lbs. per square inch, and is reduced to a working pressure of 200 lbs. The engine is of very reasonable dimensions, and is guaranteed to haul thirty-two trucks weighing one ton each on a grade of 1 in 60,—very good work for such a machine.

When used in the warm atmosphere of a mine and when properly designed, the chief drawback attending the use of air under pressure, namely, the liability to freezing as the air is expanded in use, is overcome, and these and dozens of similar locomotives are to-day doing good work in America and elsewhere. In practice it is found that the locomotives can work for considerable distances, and can stay away from the charging stations for comparatively long periods; they are, moreover, weight for weight, quite as powerful, if not more so, than corresponding steam locomotives.

Figs. 32 and 33 show a couple of double and triple-tank designs of the H. K. Porter Company, of Pittsburgh, one of the leading American makers of this class of locomotives.

AIR POWERED CARS inventor; Terry Miller

My air car invention has six complete sets of documented performance figures, obtained in six different cities by six different groups of ultra-reliable people. These figures were duly published in leading newspapers as documented facts on performance. Also, this was done in a period of only seven days and with no mechanical malfunction of my machine. Different newspaper people learned how to drive my car and were turned loose to report the facts and figures.

The following newspapers can attest to the documentation tests and their publication dates are:

The Columbus Daily Advocate, Columbus, Kansas 66725, Phone 316-429-2773, published June 19, 1980;

The Baxter Springs Citizen, Baxter Springs, Kansas 66713, Phone 316-856-2115, published June 23, 1980;

Miami News-Record, Miami, Oklahoma 74354, Phone 918-542-5533, published June 29, 1980;

The Carthage Press, Carthage, Missouri 64836, Phone 417-358-2191, published June 26, 1980;

The Chanute Tribune, Chanute, Kansas 66720, Phone 316-431-4100, published June 27, 1980;

The Coffeyville Journal, Coffeyville, Kansas 67337, Phone 316-251-3300, published June 27, 1980.

No other air powered vehicle has ever been able to be demonstrated from one coast to the other in the following cities:

Crestline, Kansas	Harrisburg, Pennsylvania	
Pittsburg, Kansas	Pittsburgh, Pennsylvania	Houston, Texas
Joplin, Missouri	New York City, New York	San Antonio, Texas
Columbus, Kansas	Baltimore, Maryland	Tuscon, Arizona
Baxter Springs, Kansas	Washington, D. C.	Phoenix, Arizona
Miami, Oklahoma	Dodge City, Kansas	San Diego, California
Carthage, Missouri	Amarillo, Texas	San Francisco, California
Chanute, Kansas	Wichita, Kansas	Sacramento, California
Coffeyville, Kansas	Kansas City, Missouri	Fresno, California
Springfield, Missouri	Tulsa, Oklahoma	Bakersfield, California
St. Louis, Missouri	Oklahoma City, Oklahoma	Los Angeles, California
Indianapolis, Indiana	Dallas, Texas	Flagstaff, Arizona
Columbus, Ohio	Fort Worth, Texas	Albuquerque, New Mexico

I have all the answers in regards to my invention to produce a town transportation car to carry two passengers; to have a range of 45 miles; to be able to be refueled with air in four minutes; to be of less total operation cost per mile than a battery powered car; to be as energy efficient as a battery car; to be able to be driven all day where a battery car can not; to speed up mid-range rather than slow down like a battery car; to absolutely not polute the air; to actually clean the air as it is used in the air station and car system; to derive considerably more miles per barrel of crude than a gasoline powered car of comparable weight; to be able to be produced promptly with no secret or unanswered technical questions yet to be solved prior to production.

A car that when used in conjuction with a wind energy air station in certain areas of the United States that would be totally one hundred per cent energy efficient using no nonrenewable fuel; a new industry that need not interfere with Detroit

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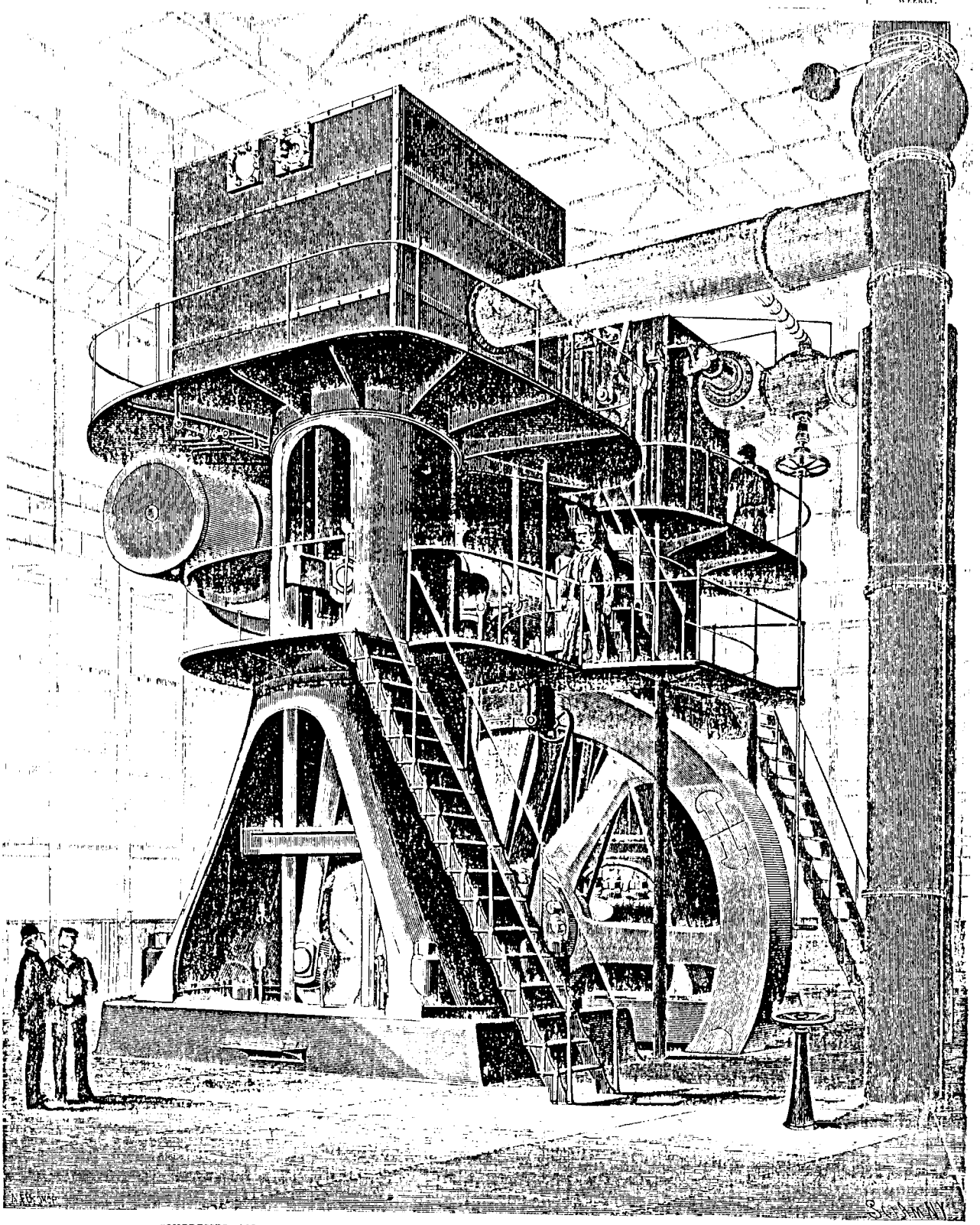

COMPRESSED AIR TRACTION IN NEW YORK CITY—1,000 HORSE POWER COMPRESSING ENGINE.—[See page 184.]